2 FREE POSTERS INSIDE

THE APOLLO PROGRAM // NEBULAE OF THE COSMOS

WIN OREGON 20x80 BINOS

All About Space

NOW FEATURING SPACE.com

50TH ANNIVERSARY

APOLLO 9

THE UNTOLD STORY

UNIVERSE GLITCH

Why does space-time unravel at its edges?

+ TAKE A GALAXY TOUR

EXOPLANET DISCOVERIES

MILKY WAY CRASH

OLDEST SOLAR SYSTEM PUZZLE SOLVED

WHAT HIT URANUS?

REVEALED! The massive force that changed an ice giant forever

MUSK GOES RETRO

INSIDE STARSHIP HOPPER

FUTURE

ISSUE 088

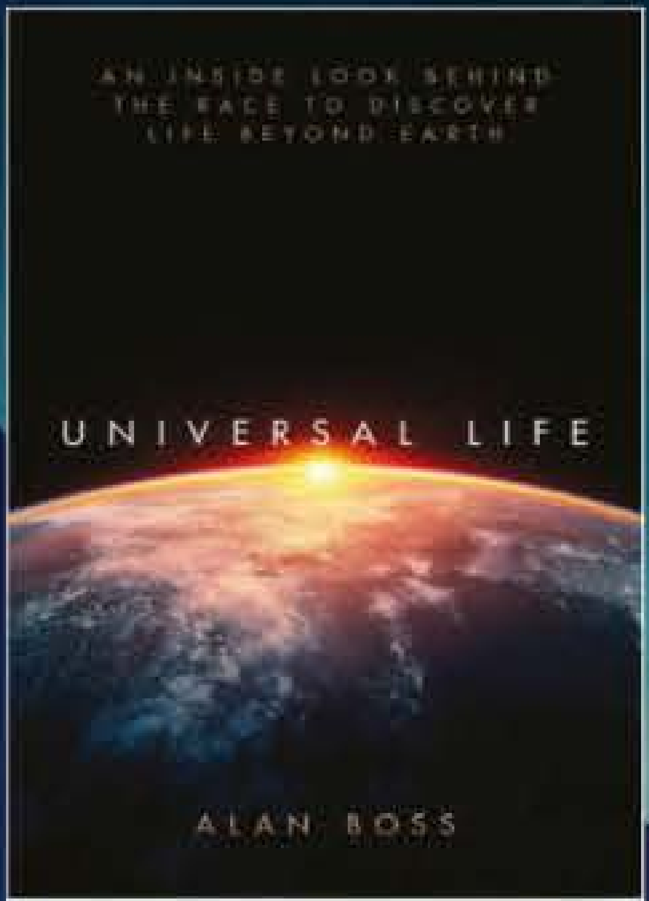
DIGITAL EDITION

NASA SCIENTISTS DEBATE

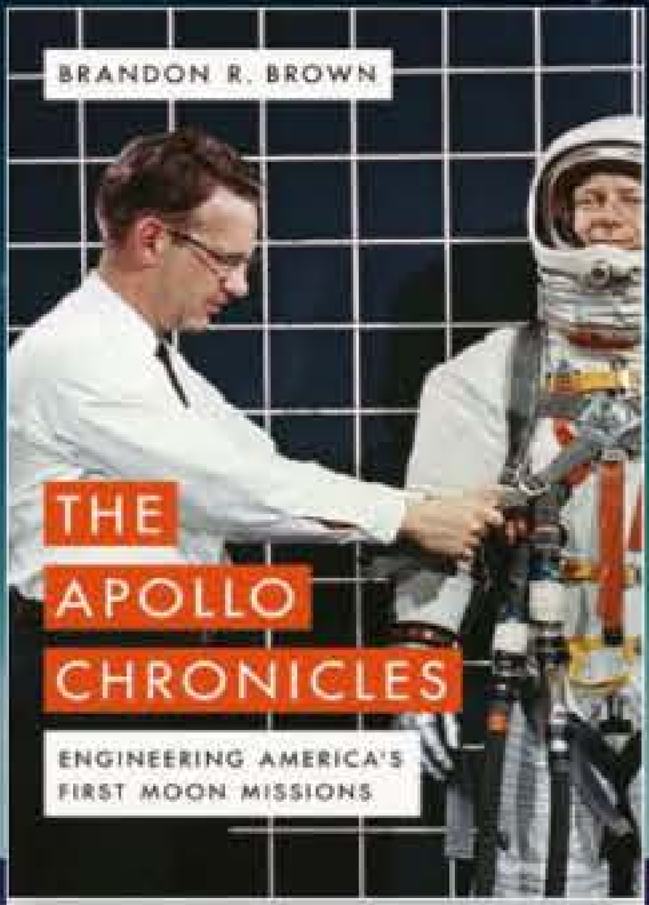
WILL THE JWST EVER LAUNCH?

New

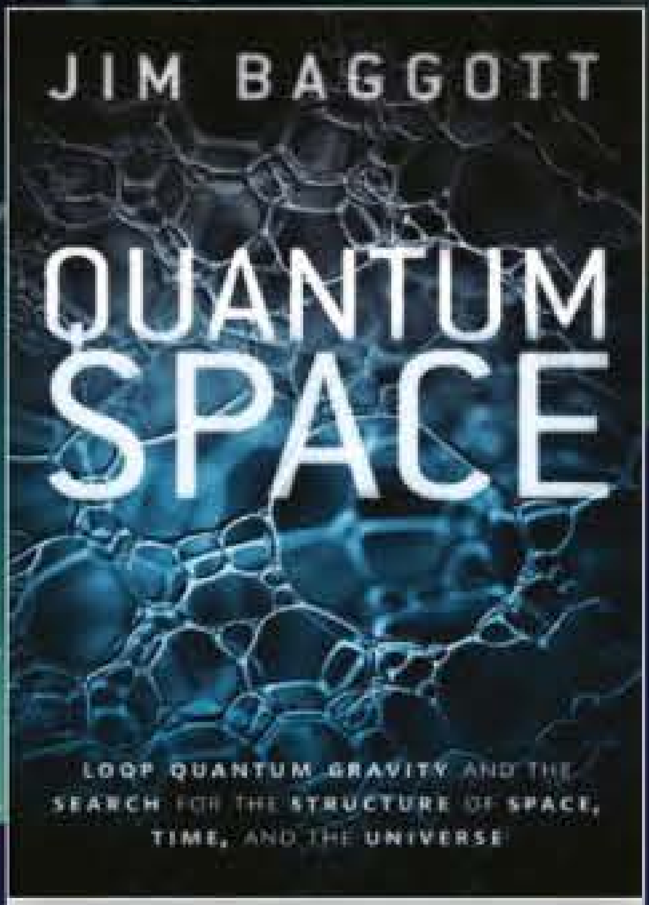
from Oxford University Press


AN INSIDE LOOK BEHIND THE RACE TO DISCOVER LIFE BEYOND EARTH
UNIVERSAL LIFE
ALAN BOSS

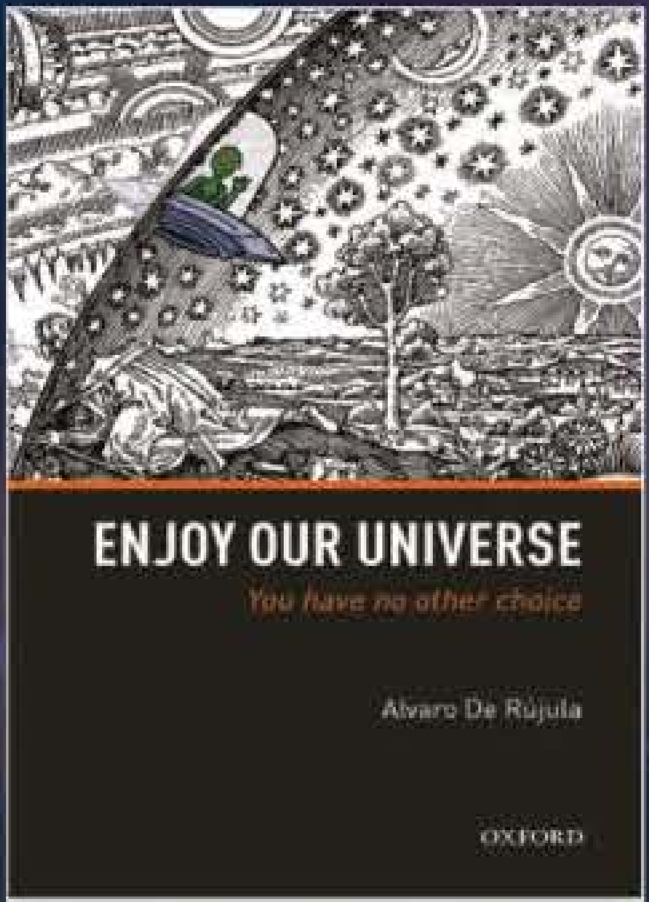
UNIVERSAL LIFE
An Inside Look Behind the Race to Discover Life Beyond Earth
Alan Boss
£16.99



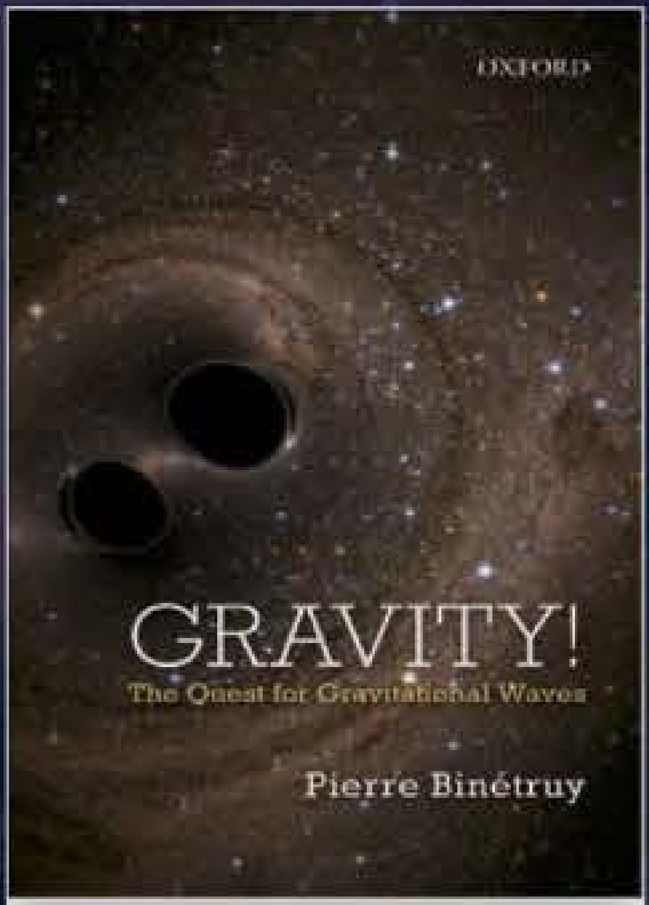
THE APOLLO CHRONICLES
Engineering America's First Moon Missions
Brandon R. Brown
£19.99


JIM BAGGOTT
QUANTUM SPACE
LOOP QUANTUM GRAVITY AND THE SEARCH FOR THE STRUCTURE OF SPACE, TIME, AND THE UNIVERSE

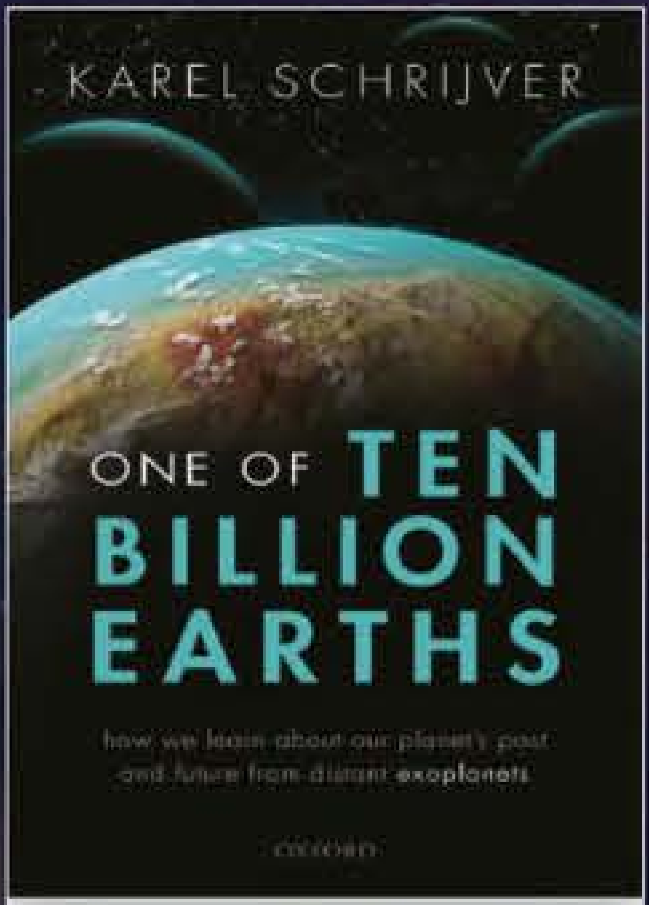
QUANTUM SPACE
Loop Quantum Gravity and the Search for the Structure of Space, Time, and the Universe
Jim Baggott
£20



ENJOY OUR UNIVERSE
You Have No Other Choice
Alvaro De Rújula
£19.99



GRAVITY!
The Quest for Gravitational Waves
Pierre Binétruy
£19.99

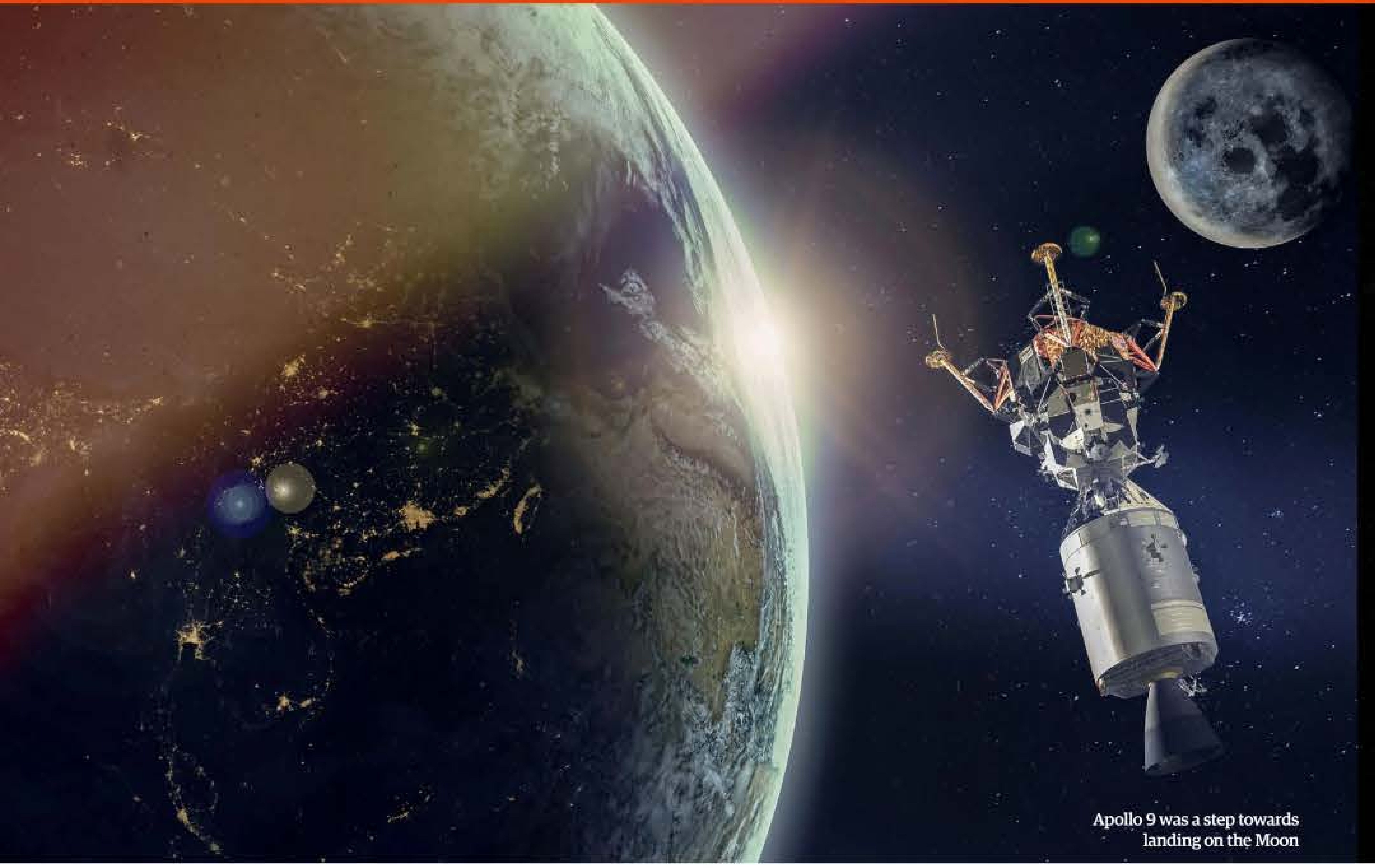

KAREL SCHRIJVER
ONE OF TEN BILLION EARTHS
how we learn about our planet's past and future from distant exoplanets
OXFORD

ONE OF TEN BILLION EARTHS
How we Learn about our Planet's Past and Future from Distant Exoplanets
Karel Schrijver
£25

Explore the full range of astronomy, cosmology and astrophysics titles at
www.oup.com/academic/physics

OXFORD
UNIVERSITY PRESS

GET FREE ALL ABOUT SPACE BONUS CONTENT
SIGN UP ONLINE AT SPACEANSWERS.COM/NEWSLETTER



Apollo 9 was a step towards landing on the Moon

Welcome

Over at **All About Space**, we're looking forward to the 50th anniversary of an incredibly important mission: the Apollo 11 Moon landing. The day that humankind first stepped foot on the lunar surface back in July 1969.

But we couldn't have got there without the help of the Apollo missions before Neil Armstrong, Buzz Aldrin and Michael Collins got blasted off into space to make history. From the tragedy of the Apollo 1 fire to Apollo 8's first manned lunar orbit, Apollo 9 is of no exception.

This issue **All About Space**'s resident writer Lee Cavendish chats to Apollo 9's Lunar Module pilot about the story of how he and fellow astronauts Commander James McDivitt and Command Module pilot David Scott put the lunar module to the test for the very first time – and in space. And that's not all; it also completed the first space docking of two vehicles with an internal crew transfer and, for ten days, the astronauts put both the future Apollo spacecraft through their paces in Earth orbit – including an undocking and redocking of the Lunar Module with the Command Service Module, just as the landing mission crew would perform in lunar orbit. It was the ultimate proof that we could achieve a manned mission to the Moon.

Speaking of Apollo, enjoy your poster of the program that changed space exploration forever.

Gemma Lavender
Editor-in-Chief

© Martin Jones / Alamy Stock Photo

Our contributors include...

Kelly Oakes
Space science writer
What hit Uranus? Kelly reports on the brand-new evidence that suggests an enormous rocky world is responsible for the ice giant's wacky behaviour.

Lee Cavendish
Staff writer
This month celebrates the 50th anniversary of Apollo 9. Lee speaks to Lunar Module pilot Rusty Schweickart about the mission's series of firsts.

Ian Evenden
Space science writer
Our Milky Way is on a collision course! Ian finds that it's not just with Andromeda – the Large Magellanic Cloud will unexpectedly cause a star-birth stir.

Abigail Beall
Space science writer
Head over to page 26 as Abigail reveals why astrophysicists think there's a glitch at the end of the universe – and what's causing space and time to unravel.

ALL ABOUT SPACE ISSUE 89 ON SALE 29 MARCH!

Available from supermarkets, newsagents and online at myfavouritemagazines.co.uk

Keep up to date

Online
www.spaceanswers.com

Facebook
/AllAboutSpaceMagazine

Twitter
@spaceanswers

CONTENTS

www.spaceanswers.com

TWEET US
@spaceanswers
POST ON FACEBOOK
/AllAboutSpaceMagazine
SEND US AN EMAIL
space@spaceanswers.com

LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE

06 Space collisions may be to blame for atmospheric development in exoplanets and Hubble discovers a living fossil in our cosmic backyard while providing its usual beautiful images and data

FEATURES

16 **What hit Uranus?**
How it became the weirdest planet in the Solar System

26 **Glitch at the end of the universe**
Why does everything unravel at the end of space and time?

34 **The Starship Hopper**
Take a look inside Elon Musk's new retro rocket, set to take you to Mars

36 **Apollo 9: The untold story**
Former crew member Rusty Schweickart relives the mission on its 50th anniversary

44 **Milky Way's big crash**
One of our satellite galaxies is travelling faster than we thought - and it's heading straight for us

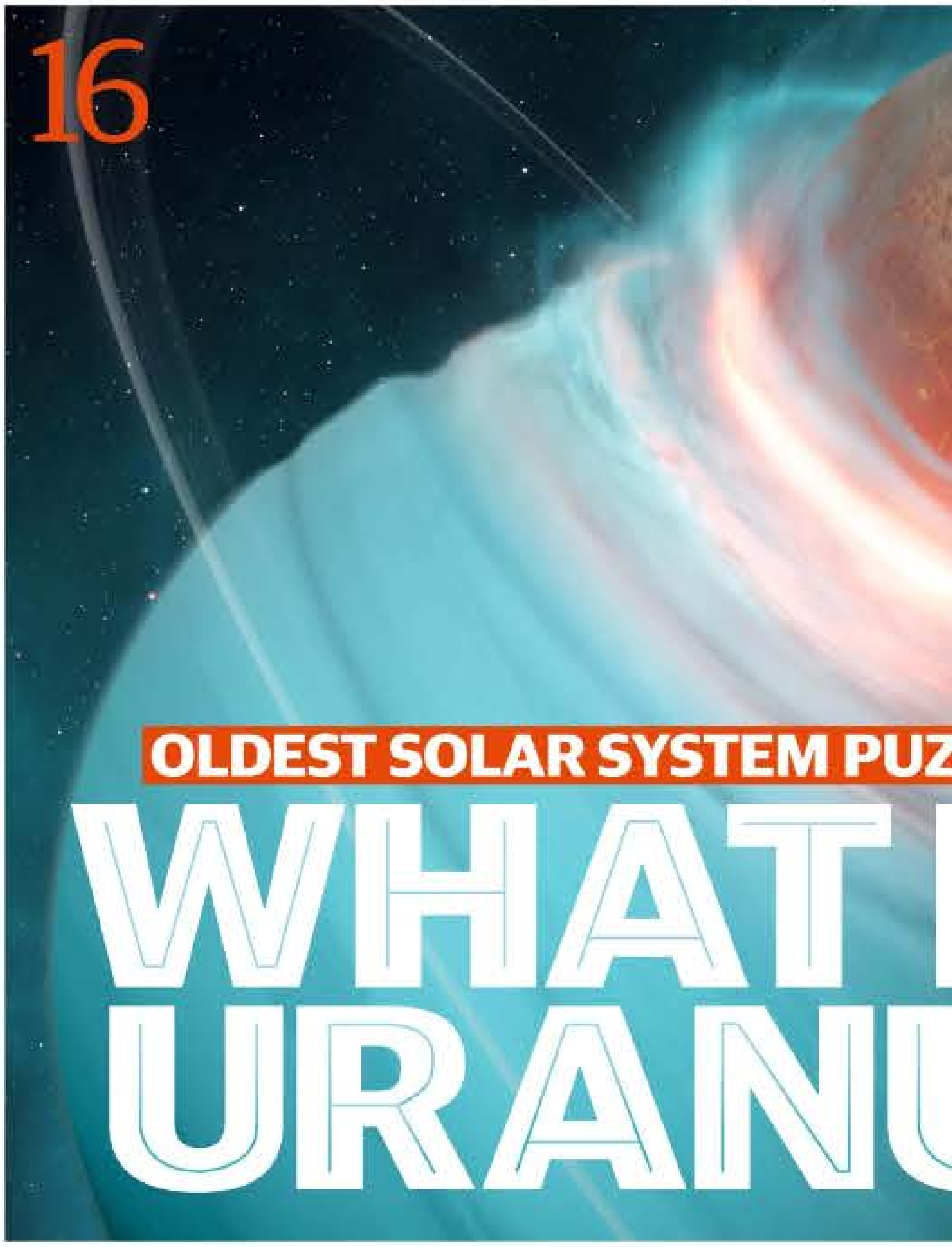
52 **Future Tech**
Next-gen telescopes
Meet NASA's great observatories of the future

54 **Ask All About Space**
Your questions answered by our experts

60 **Will the JWST ever launch?**
NASA scientists join a debate about the delayed telescope

66 **Interview**
New super-Earth discovery
Dr Diana Dragomir reveals more about her exciting exoplanet finding

70 **Instant Expert**
Redshift
Everything you need to know in five minutes



FREE KITSOUND CUBE PORTABLE BLUETOOTH SPEAKER

WORTH £19.99

TURN TO **PAGE 24** FOR DETAILS

> "It's nice to be a part of the dawn of TESS, and I'm excited for what's coming next"

66 Dr Diana Dragomir
Hubble Fellow at Massachusetts Institute of Technology

ZZLE SOLVED

HIT US?

26

THE GLITCH AT THE END OF THE UNIVERSE

34

STARSHIP HOPPER

44

BIG MILKY WAY CRASH

STARGAZER

Your complete guide to the night sky

72 **What's in the sky?**
Make the most of the last set of longer nights with a selection of observational targets

76 **Planets on display**
Venus, Jupiter and Saturn shine bright together before dawn, while Mars rules the evening

78 **Moon tour**
Posidonius lies on the northeast of Mare Serenitatis and has interesting features on its floor

79 **This month's naked eye targets**
Split Mizar and Alcor – the Big Dipper's double

80 **Galaxy Tour**
Spring is a great time to seek out the galactic treasures of Leo, Virgo and Ursa Major

86 **How to... Use Stellarium**
Our guide to one of the best planetarium programs available

88 **Deep sky challenge**
What lies hidden among the stars of 'the King' of constellations?

90 **The Northern Hemisphere**
The Great Bear and its treasures sparkle overhead

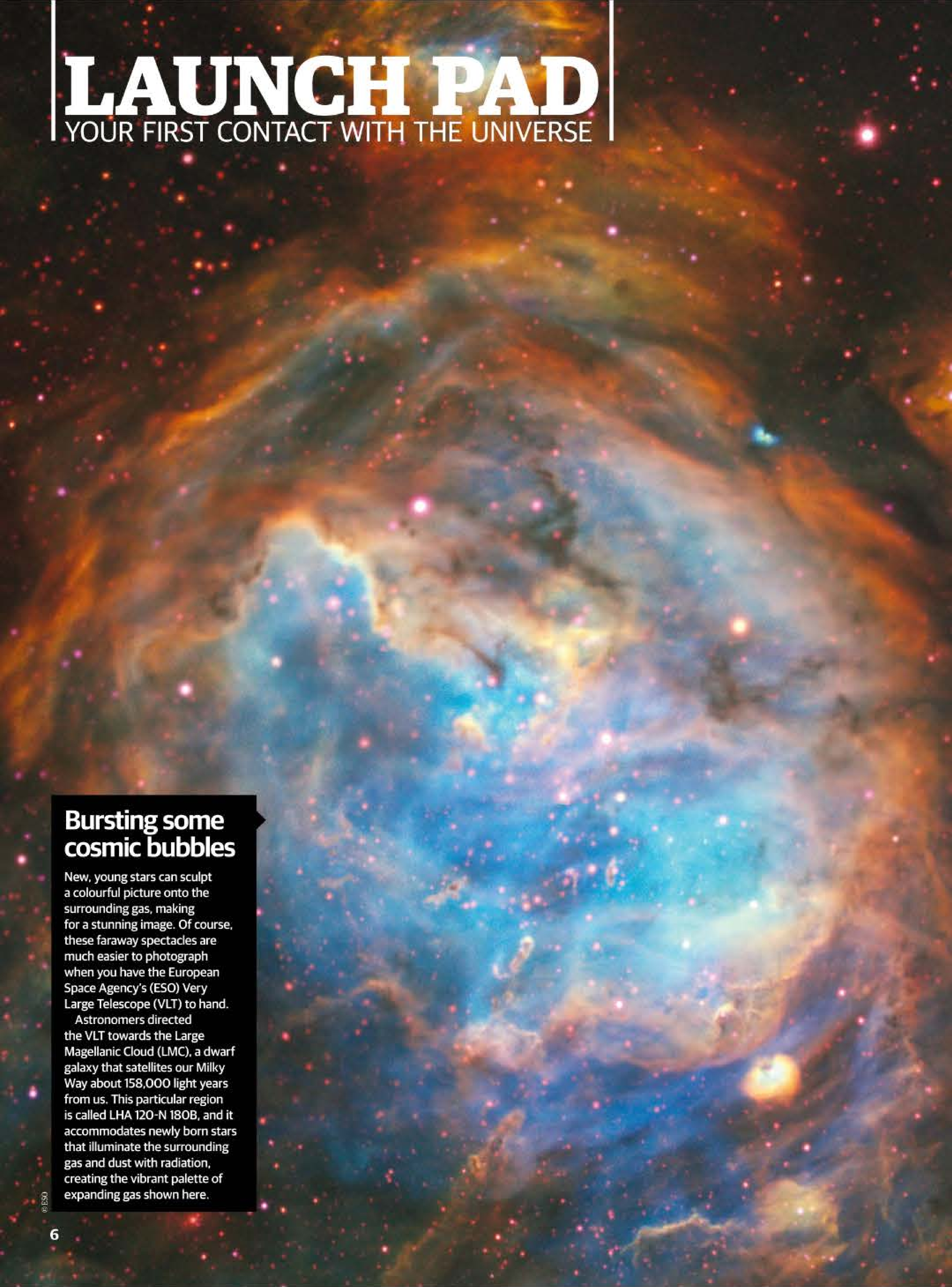
92 **Astrophotos of the month**
The best of our readers' astrophotography

96 **In the Shops**
Our pick of the best books, apps, software and accessories

WIN!

85 OREGON 20X80 BINOCULARS

WORTH £149!

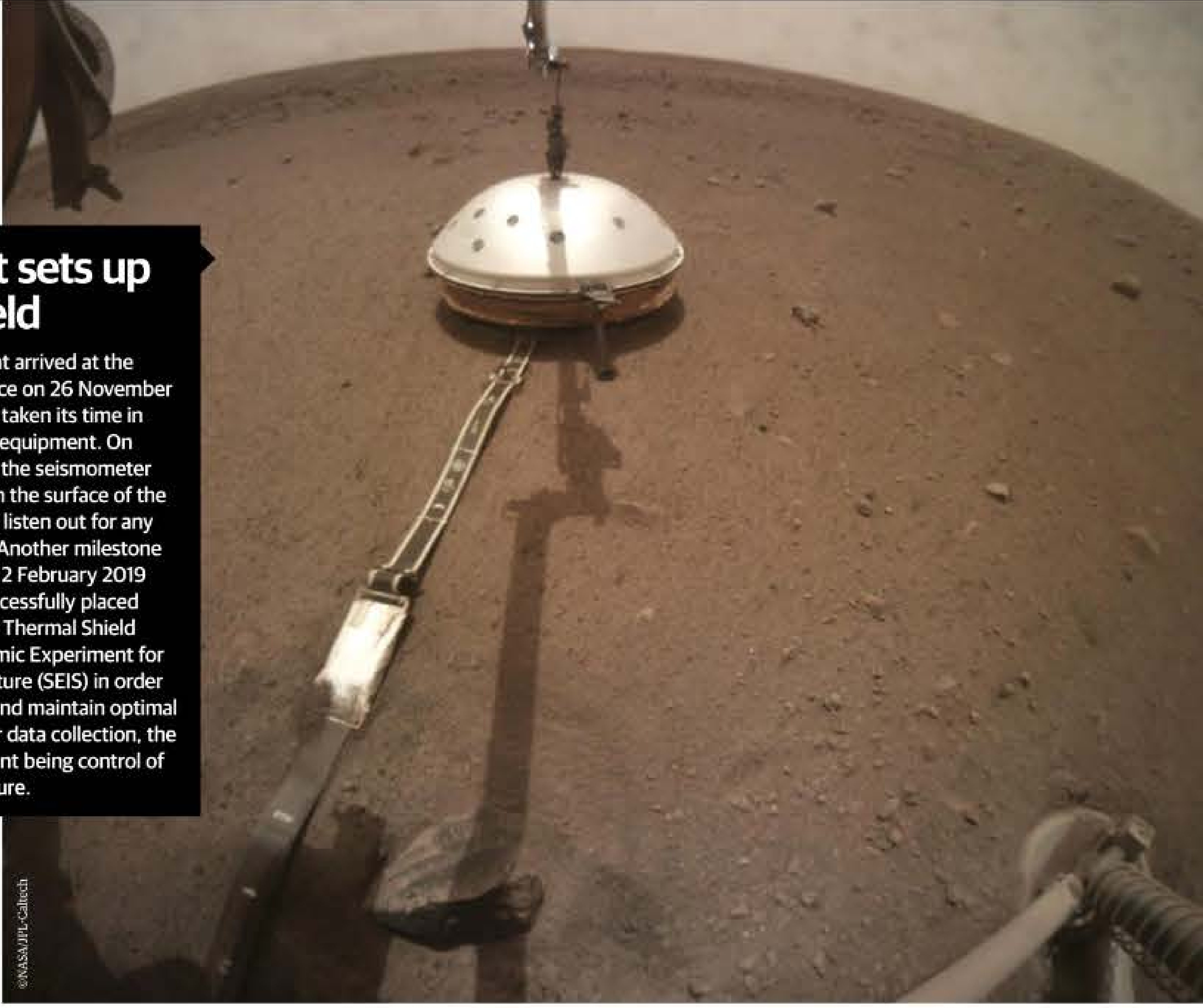


Bursting some cosmic bubbles

New, young stars can sculpt a colourful picture onto the surrounding gas, making for a stunning image. Of course, these faraway spectacles are much easier to photograph when you have the European Space Agency's (ESO) Very Large Telescope (VLT) to hand.

Astronomers directed the VLT towards the Large Magellanic Cloud (LMC), a dwarf galaxy that satellites our Milky Way about 158,000 light years from us. This particular region is called LHA 120-N 180B, and it accommodates newly born stars that illuminate the surrounding gas and dust with radiation, creating the vibrant palette of expanding gas shown here.

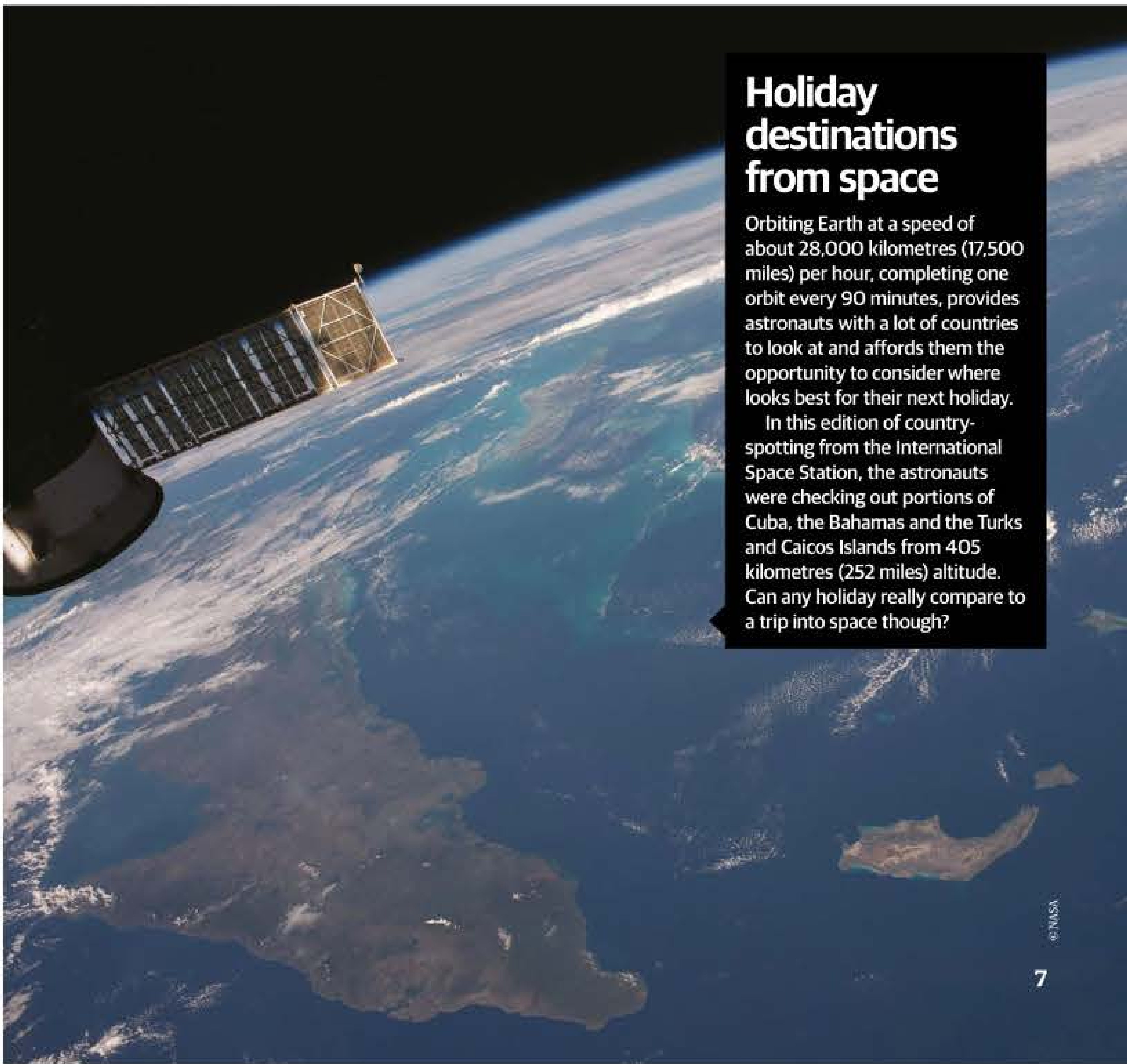
© ESO



©NASA/JPL-Caltech

InSight sets up its shield

NASA's InSight arrived at the Martian surface on 26 November 2018 and has taken its time in setting up its equipment. On 19 December the seismometer was placed on the surface of the Red Planet to listen out for any Marsquakes. Another milestone was made on 2 February 2019 as InSight successfully placed the Wind and Thermal Shield over the Seismic Experiment for Interior Structure (SEIS) in order to protect it and maintain optimal conditions for data collection, the most important being control of the temperature.



© NASA

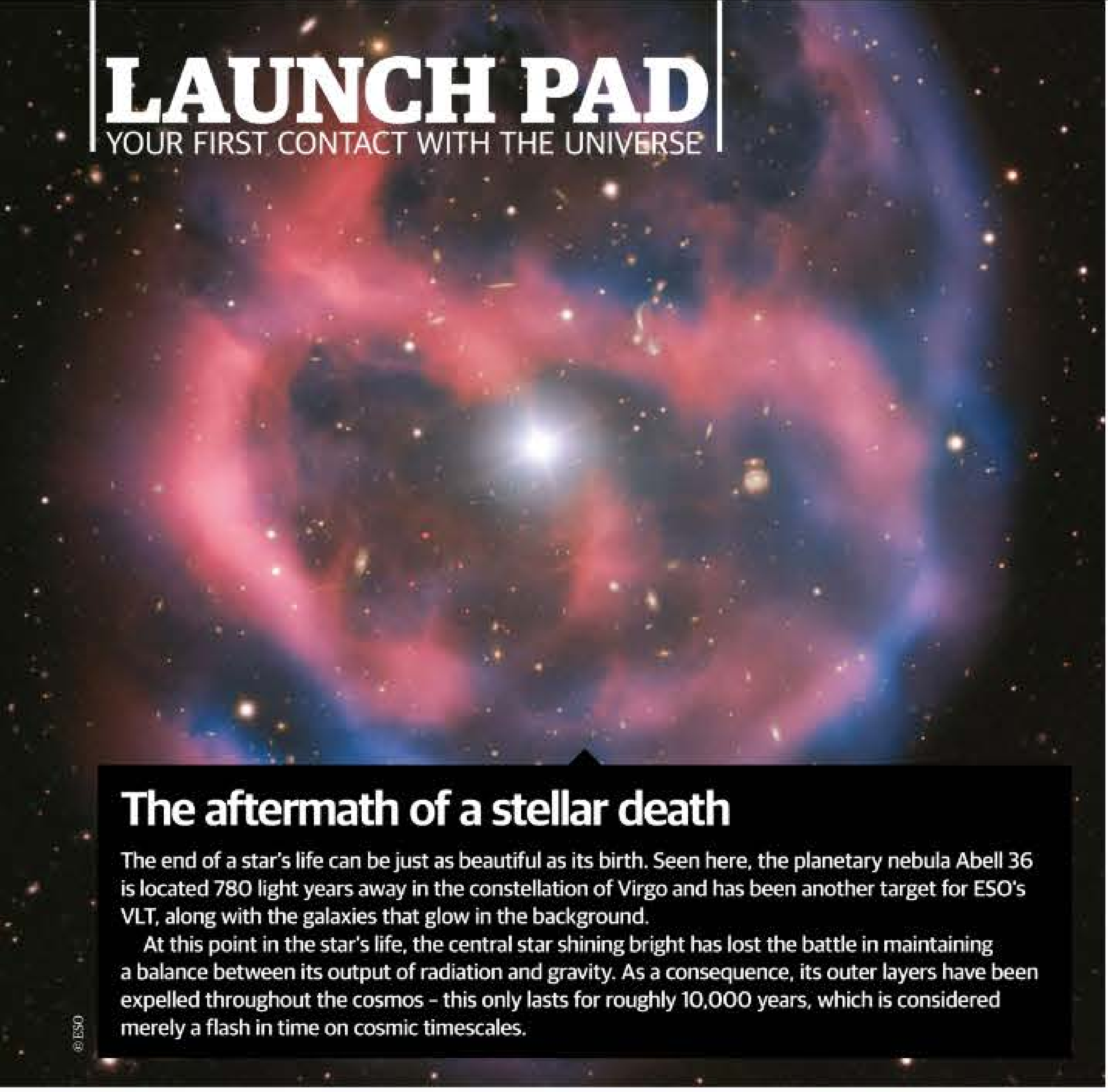
Holiday destinations from space

Orbiting Earth at a speed of about 28,000 kilometres (17,500 miles) per hour, completing one orbit every 90 minutes, provides astronauts with a lot of countries to look at and affords them the opportunity to consider where looks best for their next holiday.

In this edition of country-spotting from the International Space Station, the astronauts were checking out portions of Cuba, the Bahamas and the Turks and Caicos Islands from 405 kilometres (252 miles) altitude. Can any holiday really compare to a trip into space though?

LAUNCH PAD

YOUR FIRST CONTACT WITH THE UNIVERSE

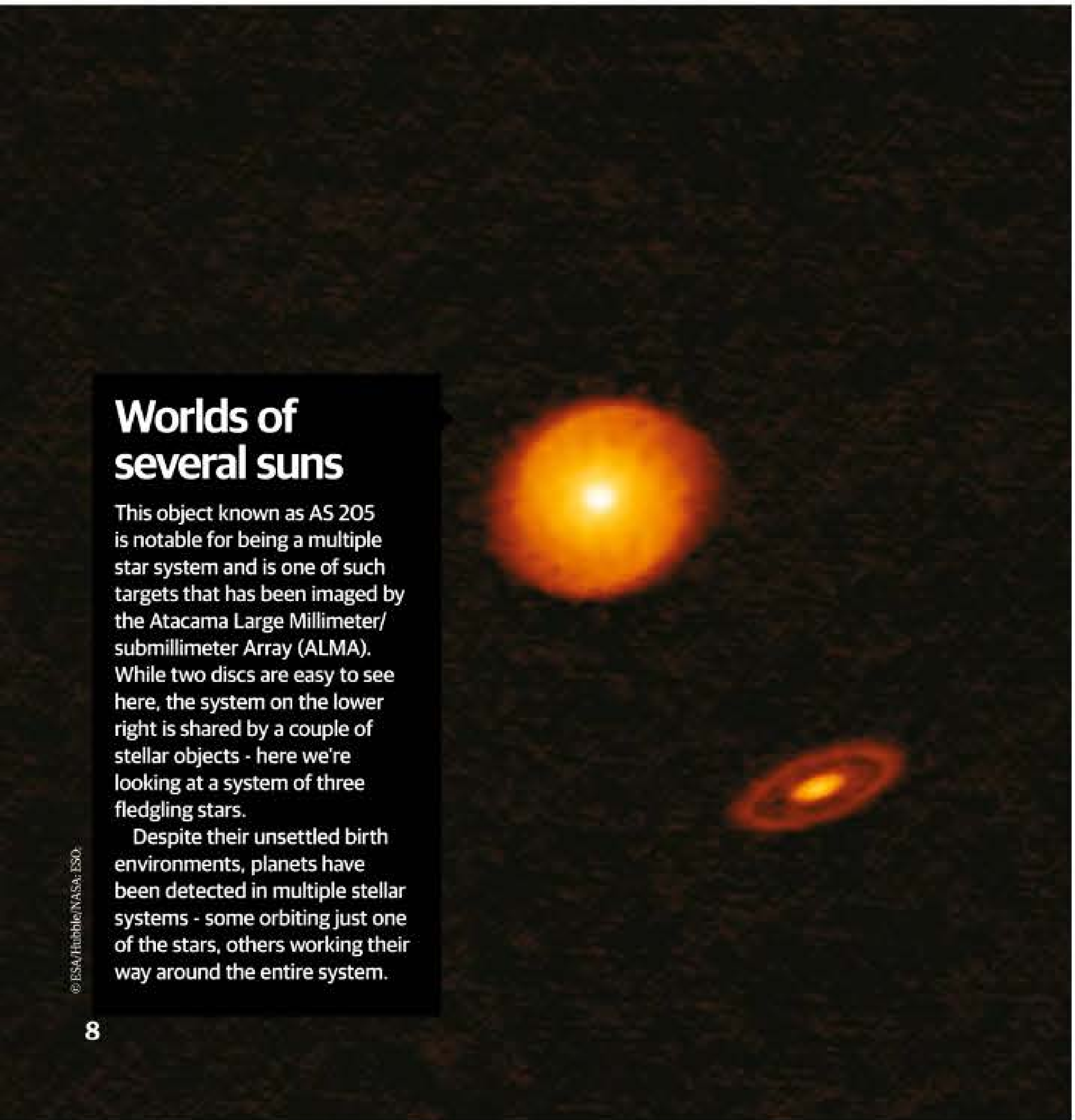


The aftermath of a stellar death

The end of a star's life can be just as beautiful as its birth. Seen here, the planetary nebula Abell 36 is located 780 light years away in the constellation of Virgo and has been another target for ESO's VLT, along with the galaxies that glow in the background.

At this point in the star's life, the central star shining bright has lost the battle in maintaining a balance between its output of radiation and gravity. As a consequence, its outer layers have been expelled throughout the cosmos - this only lasts for roughly 10,000 years, which is considered merely a flash in time on cosmic timescales.

© ESO

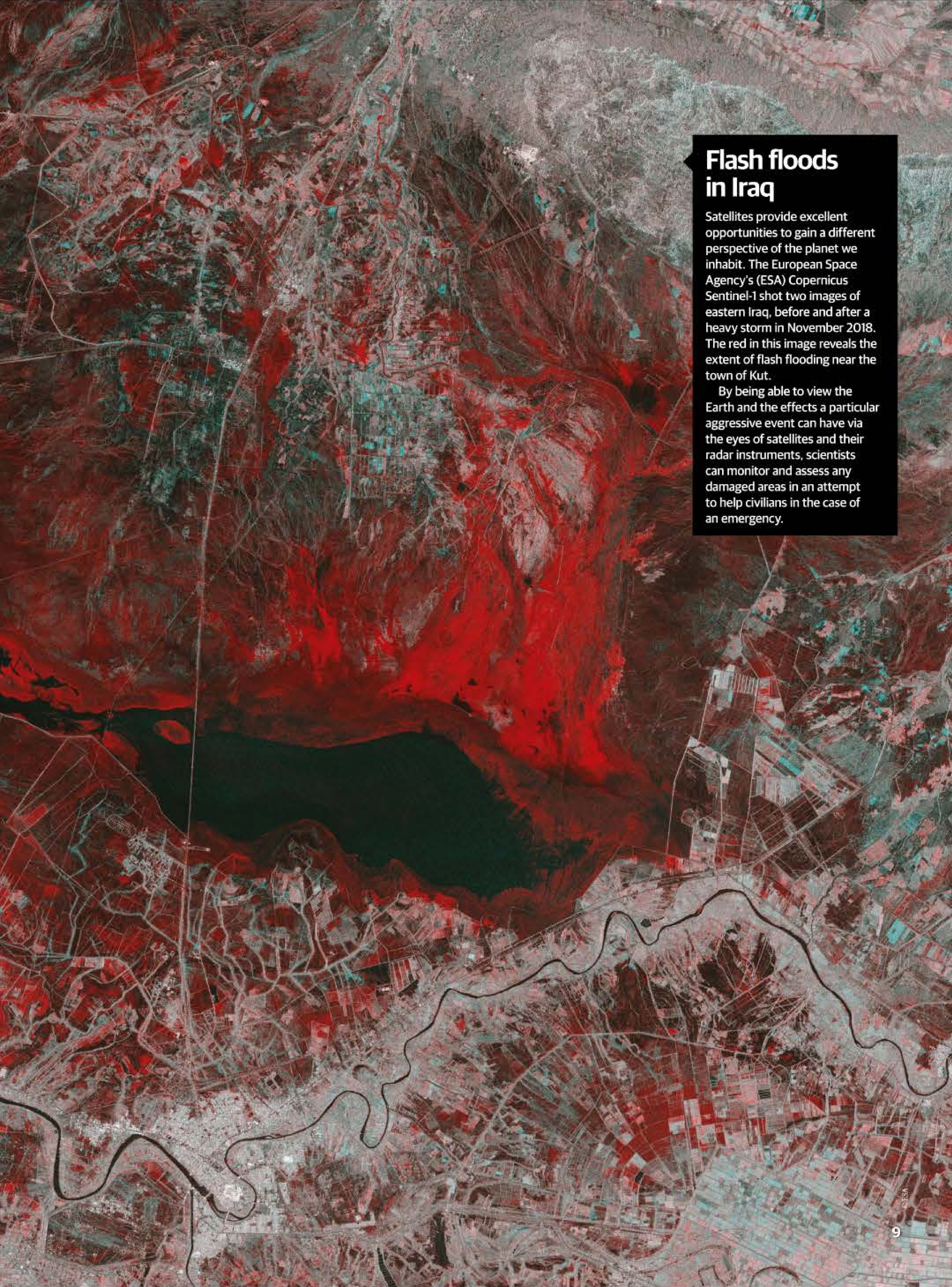


Worlds of several suns

This object known as AS 205 is notable for being a multiple star system and is one of such targets that has been imaged by the Atacama Large Millimeter/submillimeter Array (ALMA). While two discs are easy to see here, the system on the lower right is shared by a couple of stellar objects - here we're looking at a system of three fledgling stars.

Despite their unsettled birth environments, planets have been detected in multiple stellar systems - some orbiting just one of the stars, others working their way around the entire system.

© ESA/Hubble/NASA; ESO.

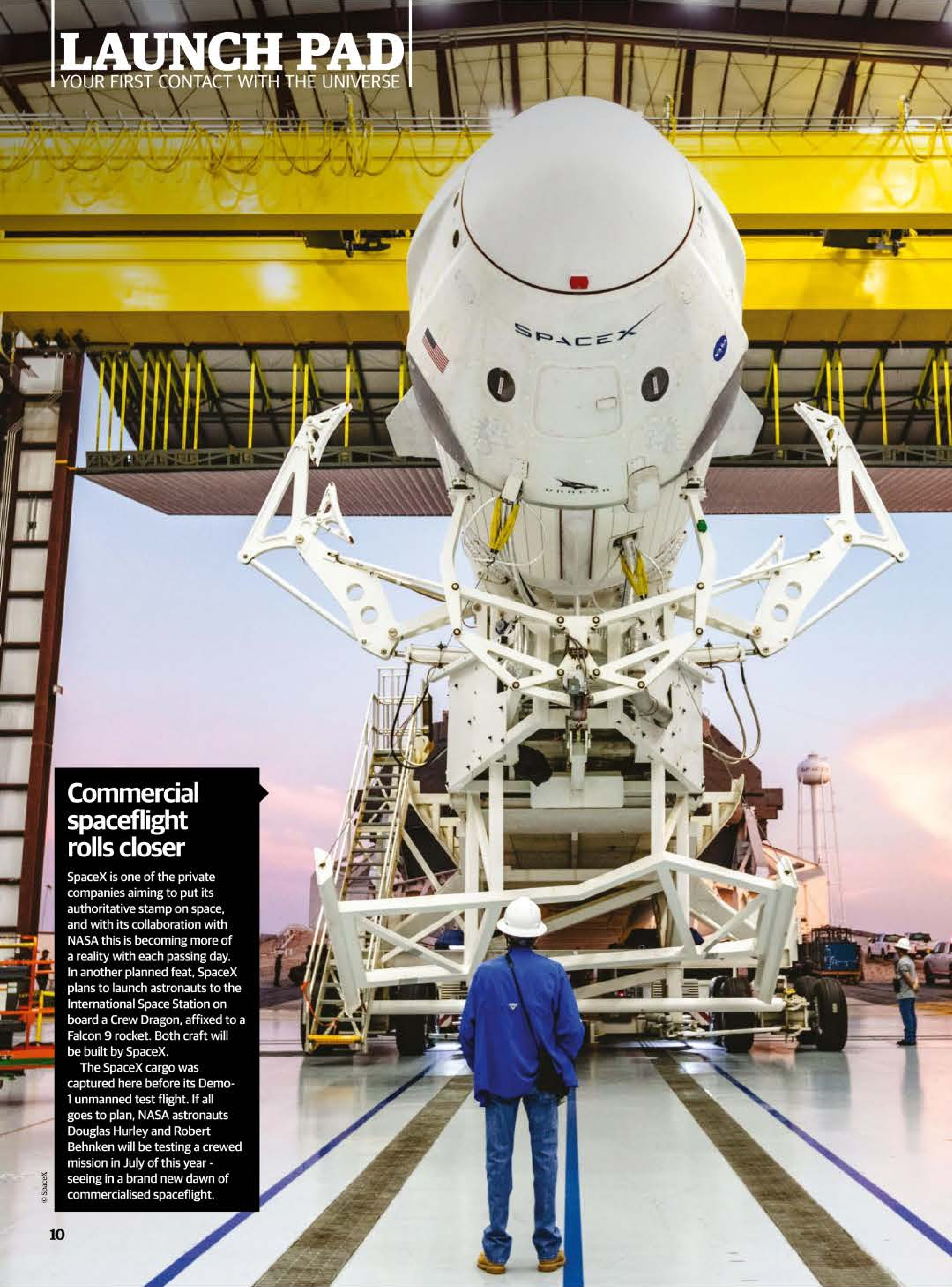


Flash floods in Iraq

Satellites provide excellent opportunities to gain a different perspective of the planet we inhabit. The European Space Agency's (ESA) Copernicus Sentinel-1 shot two images of eastern Iraq, before and after a heavy storm in November 2018. The red in this image reveals the extent of flash flooding near the town of Kut.

By being able to view the Earth and the effects a particular aggressive event can have via the eyes of satellites and their radar instruments, scientists can monitor and assess any damaged areas in an attempt to help civilians in the case of an emergency.

© ESA

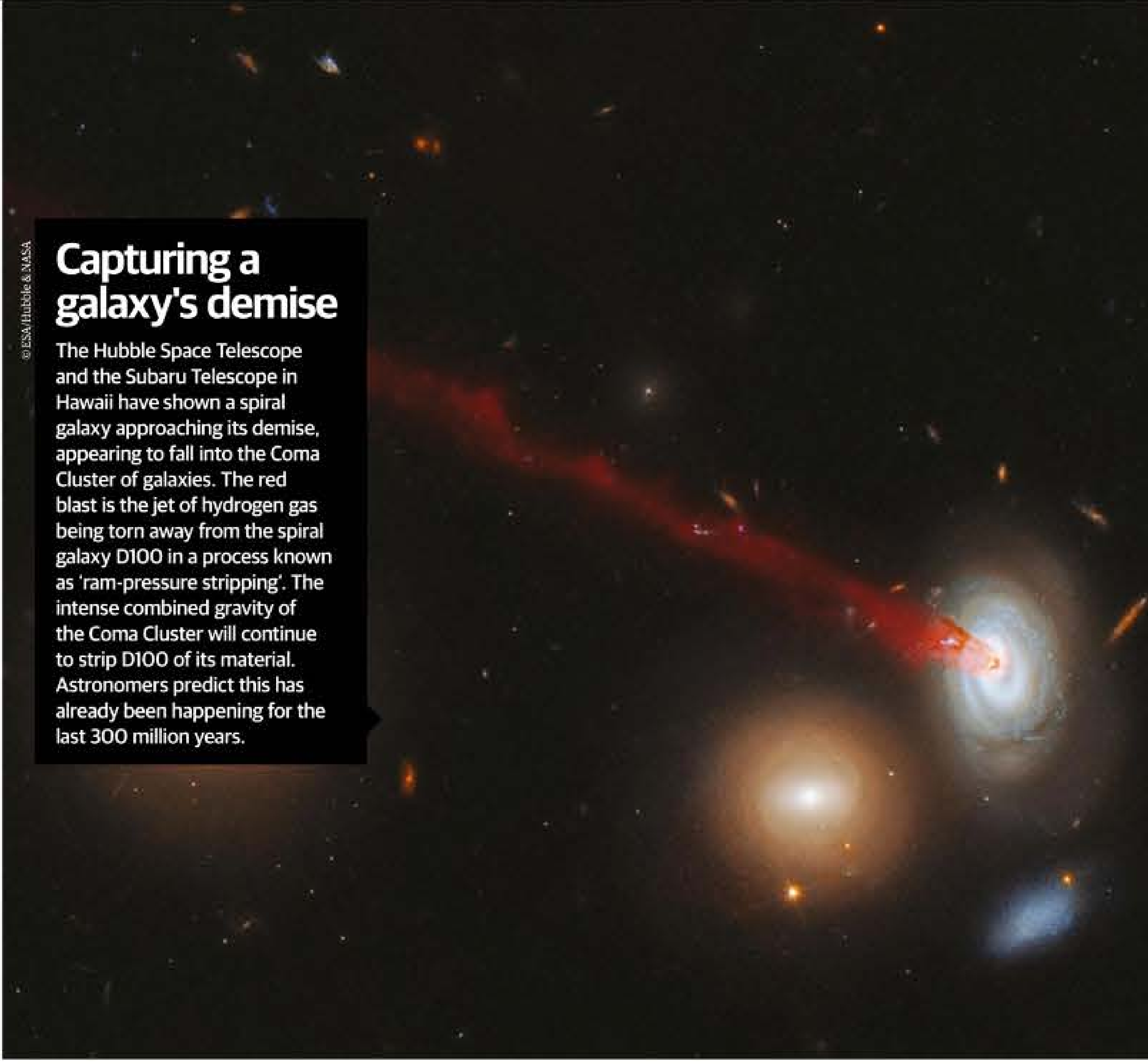


Commercial spaceflight rolls closer

SpaceX is one of the private companies aiming to put its authoritative stamp on space, and with its collaboration with NASA this is becoming more of a reality with each passing day. In another planned feat, SpaceX plans to launch astronauts to the International Space Station on board a Crew Dragon, affixed to a Falcon 9 rocket. Both craft will be built by SpaceX.

The SpaceX cargo was captured here before its Demo-1 unmanned test flight. If all goes to plan, NASA astronauts Douglas Hurley and Robert Behnken will be testing a crewed mission in July of this year - seeing in a brand new dawn of commercialised spaceflight.

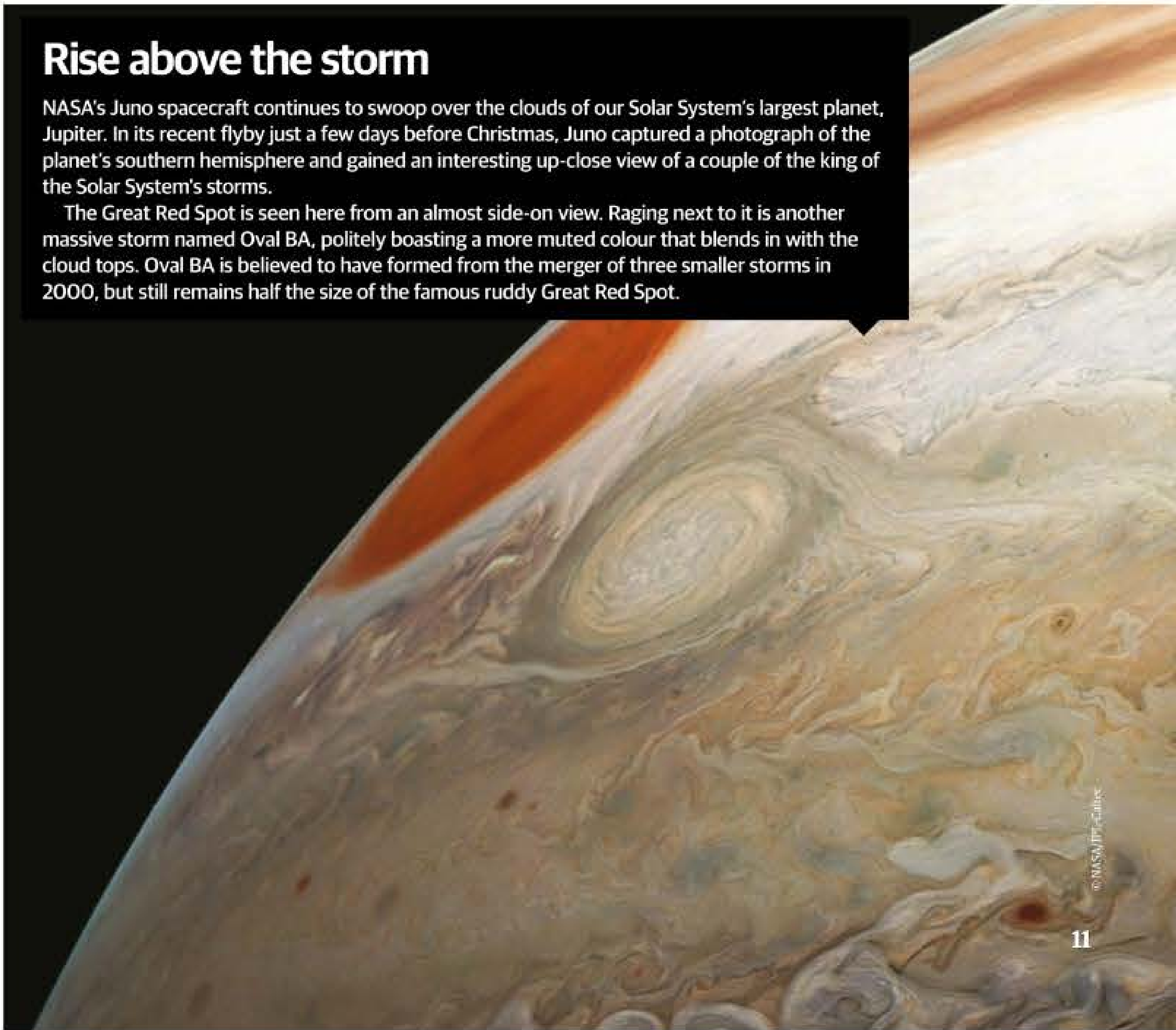
© SpaceX



Capturing a galaxy's demise

The Hubble Space Telescope and the Subaru Telescope in Hawaii have shown a spiral galaxy approaching its demise, appearing to fall into the Coma Cluster of galaxies. The red blast is the jet of hydrogen gas being torn away from the spiral galaxy D100 in a process known as 'ram-pressure stripping'. The intense combined gravity of the Coma Cluster will continue to strip D100 of its material. Astronomers predict this has already been happening for the last 300 million years.

© ESA/Hubble & NASA



Rise above the storm

NASA's Juno spacecraft continues to swoop over the clouds of our Solar System's largest planet, Jupiter. In its recent flyby just a few days before Christmas, Juno captured a photograph of the planet's southern hemisphere and gained an interesting up-close view of a couple of the king of the Solar System's storms.

The Great Red Spot is seen here from an almost side-on view. Raging next to it is another massive storm named Oval BA, politely boasting a more muted colour that blends in with the cloud tops. Oval BA is believed to have formed from the merger of three smaller storms in 2000, but still remains half the size of the famous ruddy Great Red Spot.

© NASA/JPL-Caltech

Planetary collisions caused changes to the atmospheres of young planets

Super-Earth smackdowns could explain diverse worlds

Words by **Nola Taylor Redd**

Catastrophic collisions may explain differences in giant rocky planets around other stars. A new study suggests that the heat generated by material smashing into a planet plays an important role in removing some or all of a planet's atmosphere. A wide variety of sizes for these deadly asteroids would explain differences seen in the more massive rocky worlds.

NASA's planet-hunting Kepler Space Telescope revealed a surprising number of worlds with sizes that fall between Earth and Neptune in relatively short orbits. By calculating the densities of the planets astronomers learned that many of them seem to boast massive hydrogen-helium atmospheres. However, these atmospheres seem to come in many different flavours, suggesting something was happening to the worlds after planetary formation.

"Giant impacts are very effective at reducing or removing the hydrogen or helium envelope," John Biersteker told his colleagues last month at the 233rd semiannual meeting of the American Astronomical Society in Seattle. Biersteker, a graduate student at the Massachusetts Institute of Technology, studied how impacts by rocky debris affected the atmosphere of young planets. He found that impacts could create many different types of worlds."This process can also produce a wide range of outcomes. This makes giant impacts a nice explanation for some of the observed distributions for the compositions of super-Earths."

After a star is born the dust- and gas-filled ring left behind begins the planetary formation process. Once gravity pulls together enough pieces to create a core the newborn planetesimal begins to collect hydrogen and helium from the leftover gas, building its primal atmosphere. Planets that are very close to their stars can be affected by stellar radiation which heats the top layers of the gas so that it escapes into space, leaving a thinner atmosphere.

Eventually the gas in the disc is piled onto planets or swept away by the star, leaving behind only dust and rock. Mixed among the small- and medium-size debris are the failed cores that weren't able to grow large enough to attract an atmosphere. When these massive objects slam into planets the collision can blow the planet's atmosphere off into space. One such collision helped to form Earth's Moon.

It turns out that you don't need a massive core to completely remove a planet's atmosphere. By simulating a variety of impacts Biersteker found that an object only a tenth the mass of the planet can blow off anywhere from 50 to 100 per cent of the hydrogen and helium surrounding the planet.

A planet's youth may also work against it when it comes to holding onto an atmosphere. When a planet is young – only a few tens of millions of years old – its core is still fully molten, with no crust to insulate it from the atmosphere. Since a hotter atmosphere is harder to hold onto, it doesn't take much of an impact to strip off some of the atmosphere. An object crashing into a planet raises the energy in the form of heat, allowing more of the atmosphere to be blown away.

Biersteker also found that the energy created by the impact was more important than the mass of what crashed into it. That means a small, fast-moving asteroid could potentially strip off more hydrogen and helium than a slower, medium-size object. The angle the impactor hits the world can also affect the energy of the impact – a head-on collision is more dangerous than a sideswipe.

© NASA; ESA; Gemini Observatory/AURA

Hubble discovers 'living fossil' galaxy in our Milky Way's backyard

Words by **Mike Wall**

The Hubble Space Telescope has discovered a dwarf galaxy in our own cosmic backyard, a mere 30 million light years from the Milky Way.

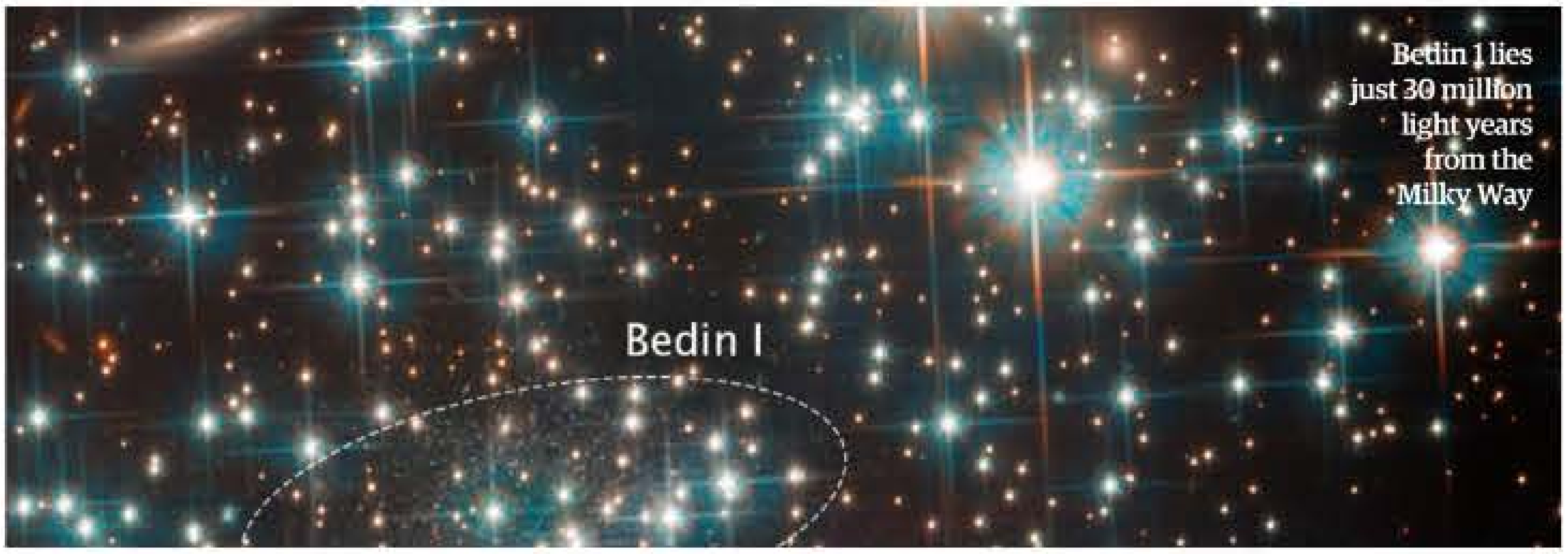
The find was fortuitous. An international team of astronomers were using Hubble's Advanced Camera for Surveys instrument to study white dwarfs - superdense stellar corpses - in the globular cluster NGC 6752, which is part of the Milky Way.

The Hubble images revealed an odd clump of stars. Analyses of the stars' brightnesses and temperatures indicated that they lay beyond NGC 6752 and were, in fact, part of a previously unknown galaxy.

The researchers determined that this galaxy - nicknamed Bedin 1 after discovery team leader L. R. Bedin of the INAF-Osservatorio Astronomico di Padova in Italy - is a spheroidal dwarf just 3,000 light years wide. For comparison, the Milky Way's famous spiral disc has a diameter of about 100,000 light years. Dwarf spheroidal galaxies are not uncommon; astronomers already knew of more than 20 that are satellites of the Milky Way. But Bedin 1 is special in several ways, according to the discovery team.

For example, the dwarf is about 2 million light years away from the closest big galaxy that could feasibly be its host, which is NCG 6744, the researchers said. Bedin 1 may therefore be the most isolated small dwarf galaxy known. And then there's Bedin 1's age.

"From the properties of its stars, astronomers were able to infer that the galaxy is around 13 billion years old - nearly as old as the universe itself," Hubble team members wrote in a statement. "Because of its isolation - which resulted in hardly any interaction with other galaxies - and its age, Bedin 1 is the astronomical equivalent of a living fossil from the early universe."



Bedin 1 lies just 30 million light years from the Milky Way

Dark energy gets weirder: mysterious force may vary over time

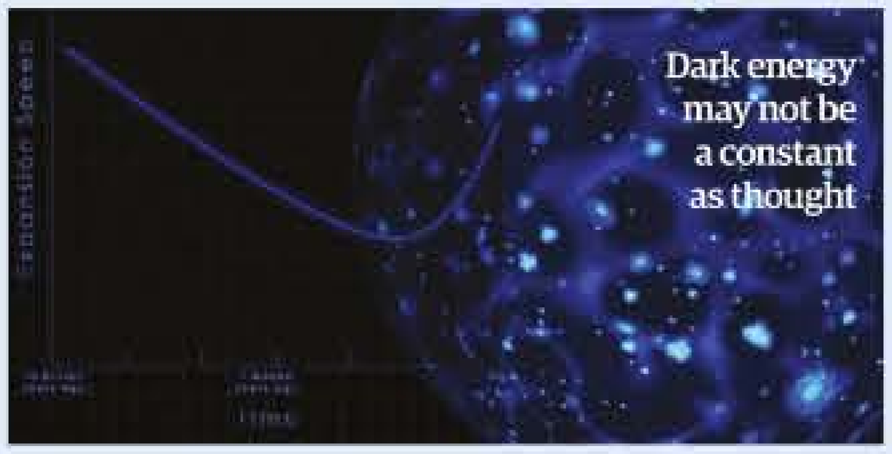
Words by **Mike Wall**

Dark energy is apparently even more mysterious than astronomers had thought. Scientists first proposed the existence of this invisible force two decades ago to explain the surprising discovery that the universe's expansion is accelerating.

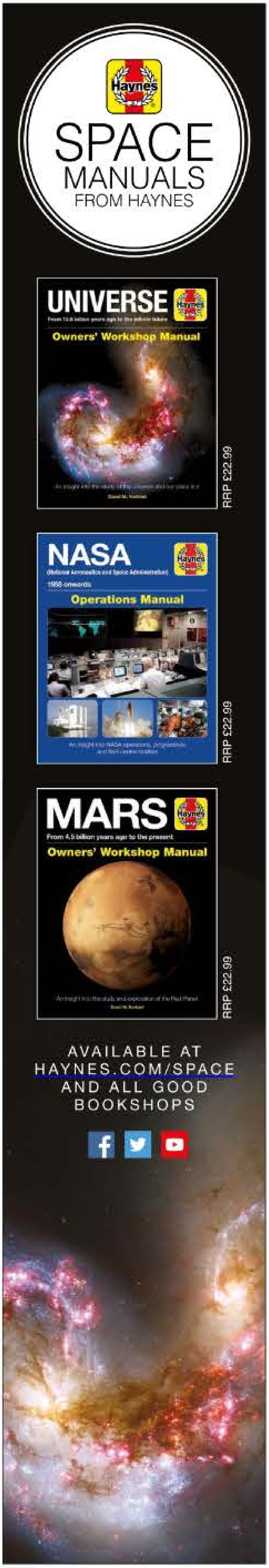
The most-used astrophysical model of the universe's structure and evolution regards dark energy as a constant. Indeed, many astronomers believe it to be the cosmological constant, which Einstein posited in 1917 as part of his theory of general relativity. But a new study of enormous, super-bright black holes known as quasars suggests that dark energy may have varied since the universe's birth 13.8 billion years ago.

"We observed quasars back to just a billion years after the Big Bang and found that the universe's expansion rate up to the present day was faster than we expected," Guido Risaliti of the University of Florence in Italy said in a statement. "This could mean dark energy is getting stronger as the cosmos grows older."

The correlation between a quasar's two types of light - ultraviolet and X-rays - can reveal the distance to a quasar, Risaliti and Elisabetta Lusso of Durham University determined. The duo examined this relationship for nearly 1,600 quasars using NASA's Chandra X-ray Observatory and the European Space Agency's XMM-Newton spacecraft to observe the quasars' X-ray light and the ground-based Sloan Digital Sky Survey to analyse the objects' UV output.



Dark energy may not be a constant as thought


Haynes
SPACE
MANUALS
FROM HAYNES

UNIVERSE
Owners' Workshop Manual
RRP £22.99

NASA
1958 onwards
Operations Manual
RRP £22.99

MARS
From 4.5 billion years ago to the present
Owners' Workshop Manual
RRP £22.99

AVAILABLE AT
HAYNES.COM/SPACE
AND ALL GOOD
BOOKSHOPS

IN COOPERATION WITH SPACE.com

'Oumuamua is still a mystery to scientist in many ways

Interstellar object 'Oumuamua could be a 'monstrous' corpse of comet dust

Words by **Meghan Bartels**

'Oumuamua, the first known visitor from beyond our Solar System, is long gone, but it's still leaving scientists guessing. A new explanation proposes that the strange object was a "monstrous fluffy dust aggregate" produced by a busted-up comet.

That's the explanation laid out by Zdenek Sekanina, an astronomer at NASA's Jet Propulsion Laboratory. The explanation draws on observations of comets breaking apart as they get closer to the Sun.

'Oumuamua is the interstellar object that astronomers detected whizzing through our Solar System in October 2017. It was the first interstellar object scientists ever spotted, although they expect thousands more have gone unnoticed. Ever since 'Oumuamua's appearance scientists have debated what the object is: asteroid or comet, ripped-up planetesimal or, the least likely, an alien probe.

The research adds another loop to the already-knotty issue by suggesting that the object changed during its brief time in our Solar System: while the object appeared reddish, long and thin during its exit, it may have started out with different properties.

'Oumuamua has been compared to other faint but more mundane comets that astronomers have observed. Typically, when these faint comets come within a quarter of Earth's distance from the Sun they don't survive the visit, experiencing an outburst that triggers their disintegration.

The research considers comet C/2017 S3 (PANSTARRS), which crept in from the Oort Cloud. This comet experienced two violent outbursts before finally falling apart – it's thought C/2017 S3's remains had become "a monstrous, extremely fluffy aggregate of loosely bound dust grains" before it made its closest approach to the Sun.

Scientists spot hint of a giant crash in alien system

Words by **Meghan Bartels**

Scientists peering at an alien solar system have spotted a pair of planets so different that their traits – namely the imbalance in their density – may be evidence of a massive collision.

The planets, which were first discovered in 2014, orbit a star called Kepler-107 with two other companions. The two innermost planets, Kepler-107 b and c, seemed to be about the same size, and scientists revisited them in order to try to determine their mass.

The planets were originally detected with the Kepler space telescope through the transit method. But a different technique commonly used to identify exoplanets is the radial velocity method, which tracks small wiggles in the star's movement that are caused by the tug of a planet's gravity – scientists can use this to estimate a world's mass.

The system is particularly intriguing because the denser planet is farther from the star than the less dense planet; in other pairs studied the reverse has been true. Researchers have come up with a handful of potential mechanisms that might result in a denser inner planet.

But those mechanisms don't make sense when the denser planet isn't the one that's closest to the star. That makes the researchers behind the new study suspect that Kepler-107 c became so dense because a giant impact stripped away outer, less dense layers of the planet.

An artist's impression of an alien solar system

Curiosity may have solved a Mars mountain mystery with gravity science

Words by **Mike Wall**

NASA's Mars rover Curiosity has flexed some scientific muscles, likely solving a Red Planet puzzle in the process. According to measurements of tiny gravitational field variations, Mount Sharp was probably built up as a free-standing mound by the deposition of windblown sand and sediment.

The car-sized rover landed on the floor of the 154-kilometre (96-mile) wide Gale Crater in August 2012, tasked with investigating the area's past potential to host life. The crater is intriguing for other reasons as well – it rises 5.5 kilometres (3.4 miles) into the Martian sky from its centre – an oddity that has no close parallel on Earth.

Kevin Lewis at Johns Hopkins University, Maryland, and his colleagues mapped out the gravitational field strength at more than 700 points along Curiosity's traverse, which has taken the rover from Gale's floor up into Mount Sharp's foothills. They discovered the density of rocks on Gale's floor to be about 1,680 kilograms (3,704 pounds) per cubic metre, meaning they're pretty porous. "It's more like a compacted soil than what you might think of as a nice, really well-cemented rock," Lewis said.

If these deposits had once been buried under five kilometres (three miles) of other sediments they would almost certainly be much denser, he added.

Curiosity is investigating the past life-hosting potential of Gale Crater

© NASA/JPL-Caltech/ESA; ESO; Michael S. Helfenbein

FEED YOUR MIND

www.howitworksdaily.com

WIN HEADPHONES WORTH £149
RADIOACTIVE POWER
Fuelling space robots to explore other worlds
HOW IT WORKS
FEATURING LIVESCIENCE
THE MAGAZINE THAT FEEDS MINDS
DEADLY PARADISE
Exploring Bolivia's beautiful but dangerous Madidi Park
HOW YOU COULD BE CLONED
What it takes to make copies of living things
REVEALED
HOW TO SURVIVE IN THE ARCTIC
WHY BIRDS EVOLVED BEAKS
WE GO INSIDE A MONEY FACTORY
IMPACT EARTH!
HOW MASSIVE METEORITES MADE HUMANKIND
PLUS THE PLAN TO SAVE OUR WORLD FROM EXTINCTION
FLYING MACHINES
Discover the wacky way helicopters take to the skies
+ INSIDE THE NEW MACBOOK AIR
YOUR CURIOUS QUESTIONS ANSWERED
NOW FEATURING LIVESCIENCE
WIN MEKAMON V2 WORTH £250
SPACE LASERS
WIN SPHERO BOLT WORTH £150
SPACE AVATARS
ROBOT MEDICINE
TSARS' PALACE EXPLORED
DOCTOR WHO
WIN! NINTENDO BUNDLE
MEET THE CARNOTAURUS
HARRY HOUDINI

HOW IT WORKS™

Available from all good newsagents and supermarkets

ON SALE NOW

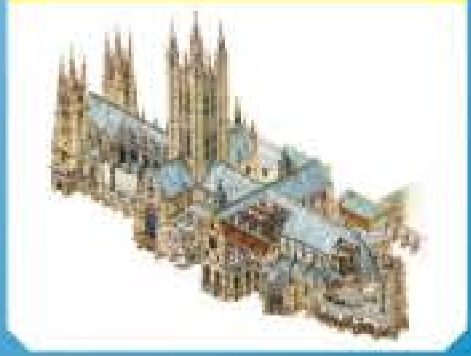
IMPACT EARTH • DEADLY PARADISE • FLYING MACHINES

SCIENCE UP CLOSE

INSIDE GADGETS

COOLEST TECH

ILLUSTRATIONS



AMAZING FACTS

BUY YOUR ISSUE TODAY

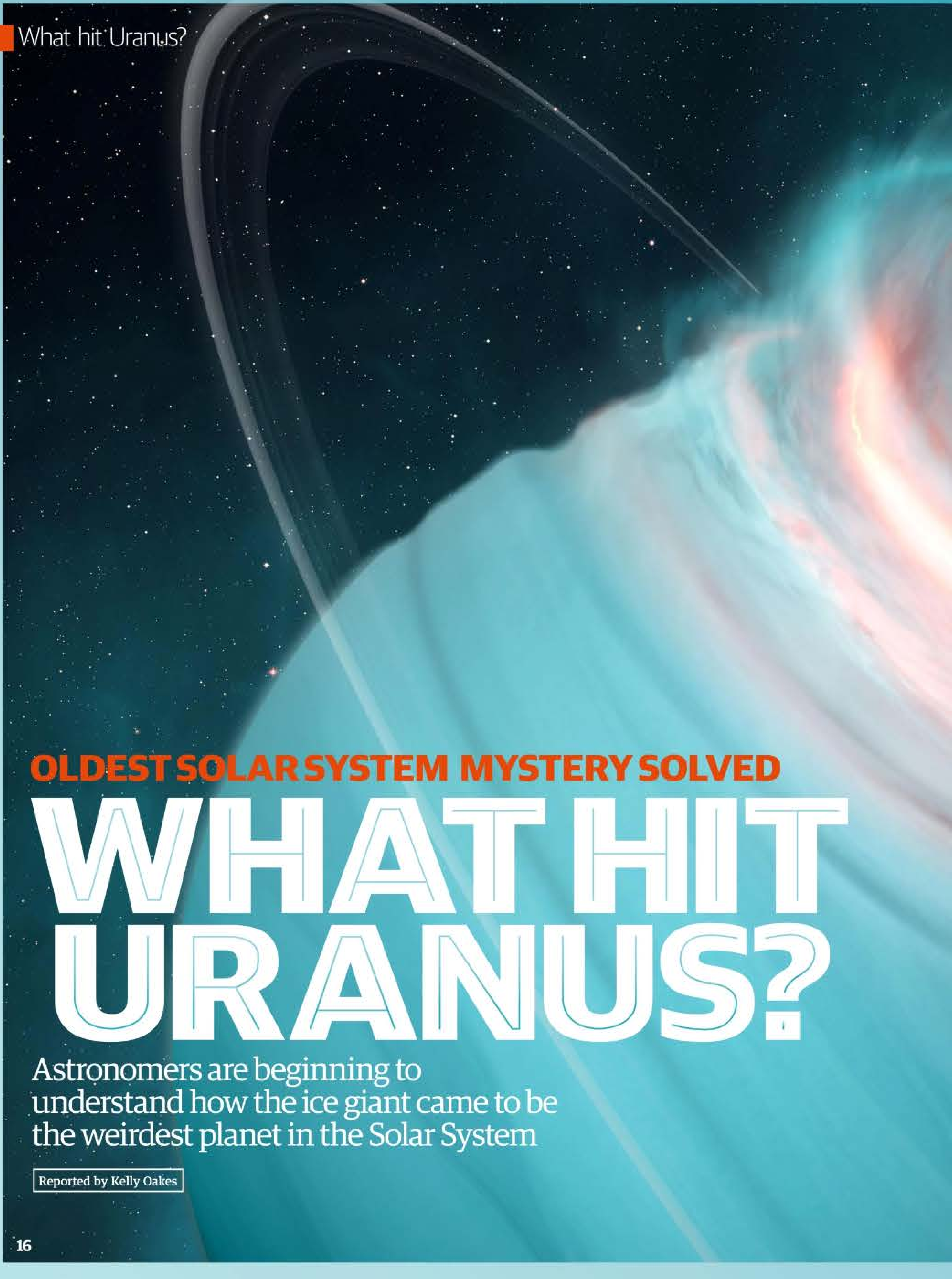
Print edition available at www.myfavouritemagazines.co.uk

Digital edition available at www.greatdigitalmags.com

Available on the following platforms

Print Tablet Phone Desktop

facebook.com/howitworks twitter.com/@howitworksmag



OLDEST SOLAR SYSTEM MYSTERY SOLVED

WHAT HIT URANUS?

Astronomers are beginning to understand how the ice giant came to be the weirdest planet in the Solar System

Reported by Kelly Oakes

The eight major planets in our Solar System are all mysterious in their own ways, but Uranus, seventh from the Sun, is particularly weird. The ice giant is tilted, its north and south poles where you would expect the planet's equator to be. Its magnetic field is off-centre. And though you'd expect an ice giant to be cold, Uranus is even colder than scientists think it should be. Now researchers are starting to unravel how it came to be this way.

Just like Saturn and Neptune, Uranus has a ring system. However, because the planet is tilted 98 degrees, its rings orbit the ice giant vertically instead of around its middle – for comparison, Earth is tilted 23 degrees, and Jupiter a mere three degrees. It also has plenty of moons, including five major ones and at least 22 other known satellites, which orbit the same way.

Aside from the moons and rings, Uranus' tilt also dramatically affects the conditions on the planet itself. The length of a day on Uranus changes a lot over the ice giant's orbit around the Sun. Each pole of Uranus spends around 42 Earth years pointing towards the Sun, while the other faces away, before they switch.

When one of the planet's poles is most directly pointing towards the Sun, called a solstice, only a small part of the planet near the equator experiences a day-night cycle, while that pole is bathed in light and the other in dark. As it orbits the Sun the planet gradually spins until eventually the other pole faces the Sun. In the middle, at the planet's equinoxes, the equator of the planet faces

> "Aside from the moons and the rings, Uranus' tilt also dramatically affects the conditions on the planet itself"

the Sun, and its day-night cycles are more similar to what we are used to on Earth.

The planet itself looks pretty blank and featureless from a distance. When the Voyager 2 spacecraft came within 81,500 kilometres (50,600 miles) of the top of Uranus' atmosphere in January 1986 - the only time we have visited the planet - it saw a smooth, turquoise expanse. But this calm exterior belies stranger things underneath.

The planet's atmosphere is mostly made up of hydrogen, helium and methane, with some other hydrocarbons, too. The methane is what gives the planet its bluish-green hue, because the gas absorbs red wavelengths of light. Though it looks calm, the Hubble Space Telescope revealed that Uranus has an active weather system with strong winds, bright clouds and even aurorae. "It's very hard to see them because the exterior is so boring; it's hard to tell what's going on," says Jacob Kegerreis, a PhD student in computational astrophysics at the University of Durham.

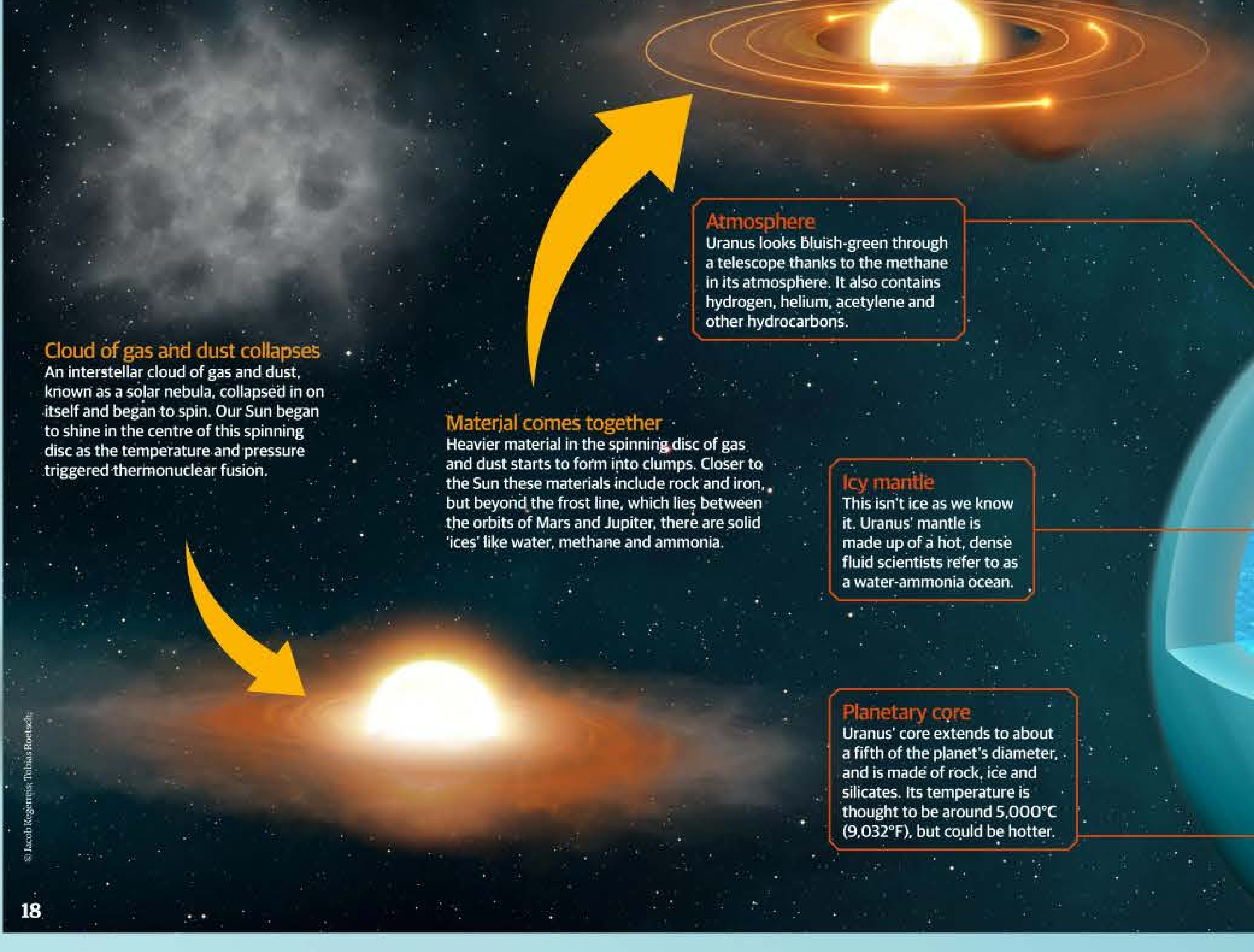
Voyager 2 sent back thousands of images and plenty of scientific data from Uranus. The spacecraft pinned down the length of time the planet takes to rotate as 17 hours, 14 minutes. It revealed the spectacular detail of the previously known rings around the planet, and discovered two new ones. As well as this the spacecraft spotted 11 previously unknown moons orbiting the planet and found evidence of geological activity on the five largest: Miranda, Ariel, Umbriel, Oberon and Titania.

Perhaps the strangest thing Voyager 2 discovered about Uranus was its strangely wonky magnetic field, tilted not at the same angle as the planet but instead at 59 degrees, and not appearing to originate from the planet's centre. This means the strength of the magnetic field in each hemisphere of the planet is different - compare that to the magnetic field strength on Earth, which is strongest at the north and south poles and weakest at the equator, and you start to understand how peculiar it is. Another as yet unexplained mystery of the planet is how cold it is. The lowest temperature recorded

> "Hubble revealed that Uranus has an active weather system with strong winds, bright clouds and even aurorae"

How an ice giant is made

Uranus formed in a similar way to the other Solar System planets before something hit it



Cloud of gas and dust collapses
An interstellar cloud of gas and dust, known as a solar nebula, collapsed in on itself and began to spin. Our Sun began to shine in the centre of this spinning disc as the temperature and pressure triggered thermonuclear fusion.

Material comes together
Heavier material in the spinning disc of gas and dust starts to form into clumps. Closer to the Sun these materials include rock and iron, but beyond the frost line, which lies between the orbits of Mars and Jupiter, there are solid 'ices' like water, methane and ammonia.

Atmosphere
Uranus looks bluish-green through a telescope thanks to the methane in its atmosphere. It also contains hydrogen, helium, acetylene and other hydrocarbons.

Icy mantle
This isn't ice as we know it. Uranus' mantle is made up of a hot, dense fluid scientists refer to as a water-ammonia ocean.

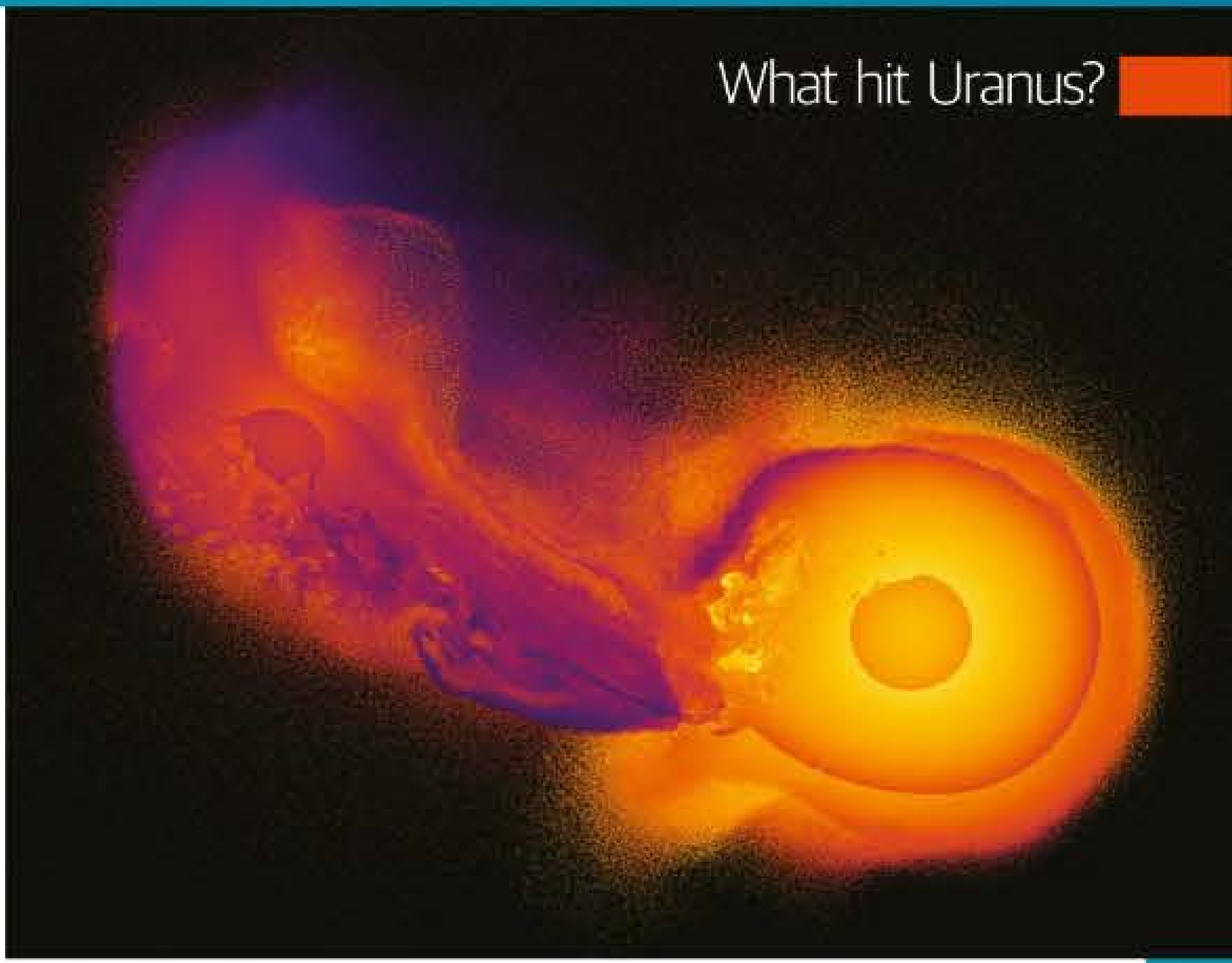
Planetary core
Uranus' core extends to about a fifth of the planet's diameter, and is made of rock, ice and silicates. Its temperature is thought to be around 5,000°C (9,032°F), but could be hotter.

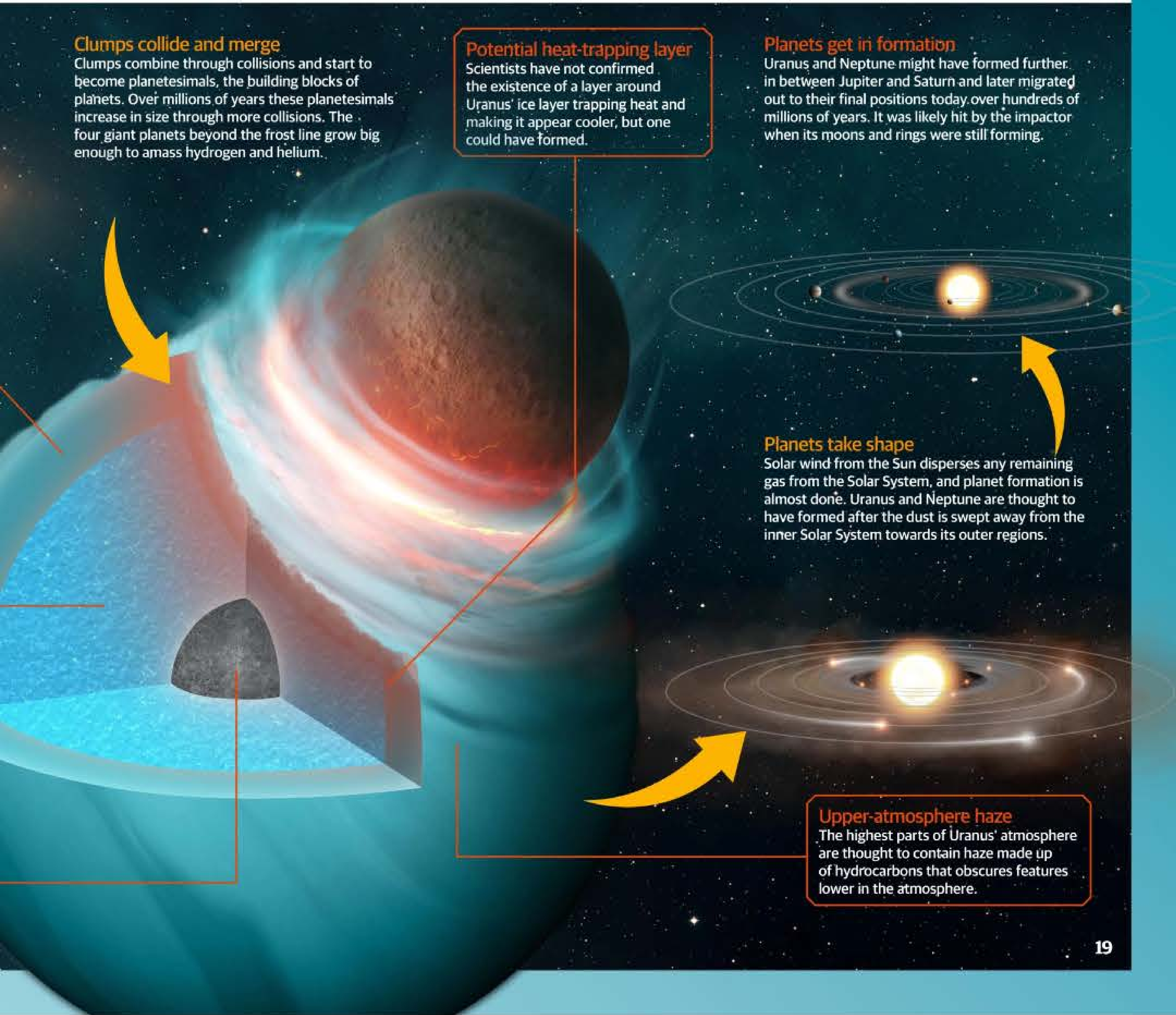
© Jacob Kegerreis; Tobias Roetsch

on Uranus is −224.2 degrees Celsius (-371.56 degrees Fahrenheit). Other planets in our Solar System radiate more heat from their centres than they get from the Sun, but Uranus barely gives out any.

The answer to both of these mysteries might lie in what happened when Uranus became tilted. Planets are born out of discs of debris that circle nascent stars. When Uranus was formed it was likely spinning not too far off centre in much the same way as other planets in the Solar System. But new star systems in the process of forming are violent, hectic places. As well as the bodies that we know as planets today, there would have been potentially tens or hundreds of protoplanets - planets in a very early stage of formation, typically made of ice and rock - flying around the early Solar System. Once the initial debris disc around the Sun had disappeared, blown away by solar wind or cobbled together into other planets, these

Right: High-resolution simulations of a giant impact on Uranus, tilting the planet to the angle we see today





Clumps collide and merge

Clumps combine through collisions and start to become planetesimals, the building blocks of planets. Over millions of years these planetesimals increase in size through more collisions. The four giant planets beyond the frost line grow big enough to amass hydrogen and helium.

Potential heat-trapping layer

Scientists have not confirmed the existence of a layer around Uranus' ice layer trapping heat and making it appear cooler, but one could have formed.

Planets get in formation

Uranus and Neptune might have formed further in between Jupiter and Saturn and later migrated out to their final positions today over hundreds of millions of years. It was likely hit by the impactor when its moons and rings were still forming.

Planets take shape

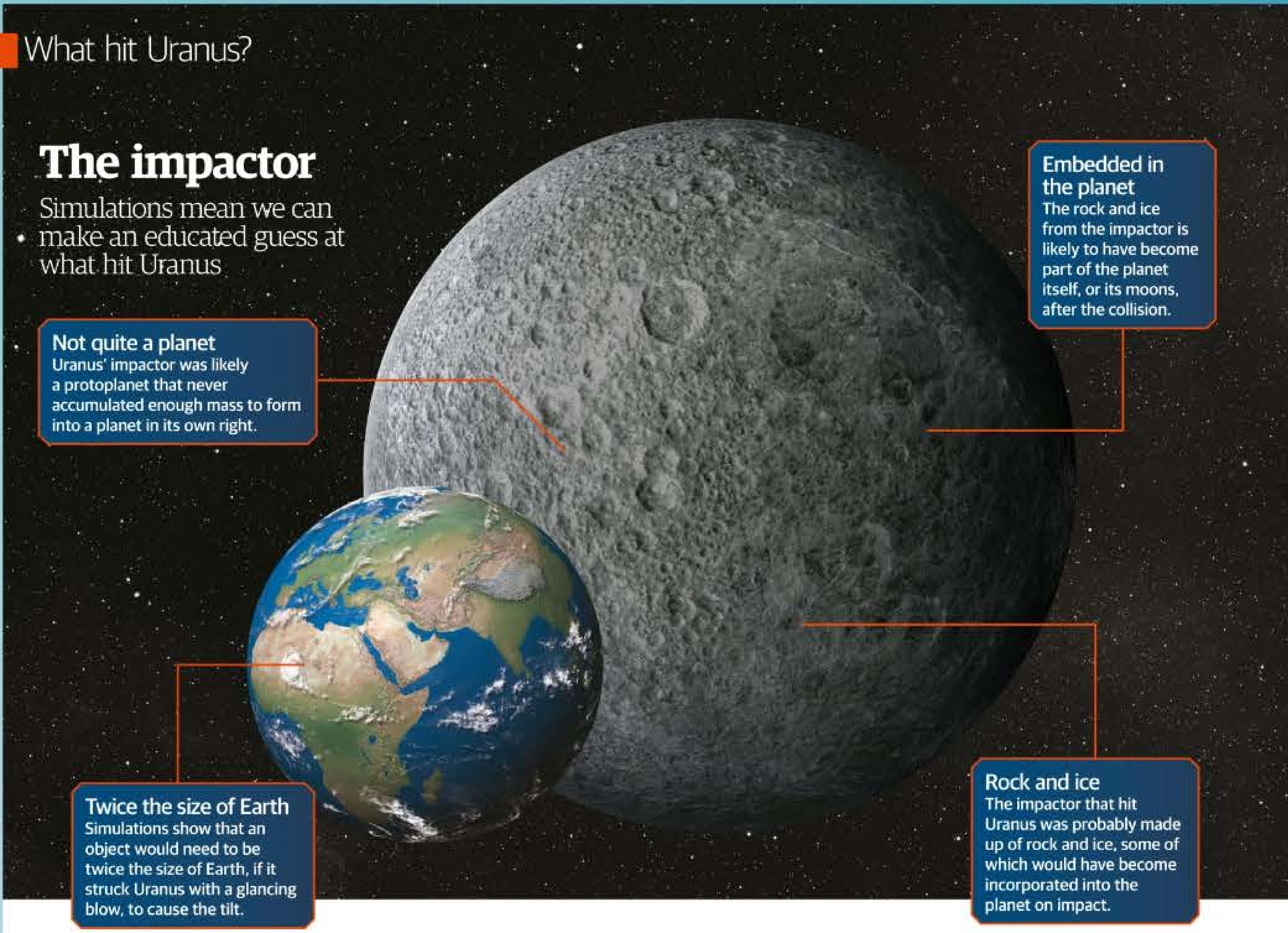
Solar wind from the Sun disperses any remaining gas from the Solar System, and planet formation is almost done. Uranus and Neptune are thought to have formed after the dust is swept away from the inner Solar System towards its outer regions.

Upper-atmosphere haze

The highest parts of Uranus' atmosphere are thought to contain haze made up of hydrocarbons that obscures features lower in the atmosphere.

The impactor

Simulations mean we can make an educated guess at what hit Uranus



Not quite a planet
Uranus' impactor was likely a protoplanet that never accumulated enough mass to form into a planet in its own right.

Embedded in the planet
The rock and ice from the impactor is likely to have become part of the planet itself, or its moons, after the collision.

Twice the size of Earth
Simulations show that an object would need to be twice the size of Earth, if it struck Uranus with a glancing blow, to cause the tilt.

Rock and ice
The impactor that hit Uranus was probably made up of rock and ice, some of which would have become incorporated into the planet on impact.

protoplanets would have become less stable and potentially ended up on collision paths with their fully grown siblings.

A protoplanetary hit job is the leading theory. "The giant-impact scenario is still the leading hypothesis to explain the high obliquity of Uranus," says Nadine Nettelman, a planetary scientist at the University of Rostock in Germany. Scientists think that as well as being responsible for the tilt of Uranus, giant impacts are to blame for other Solar System phenomena, including Earth's own Moon and Saturn's rings.

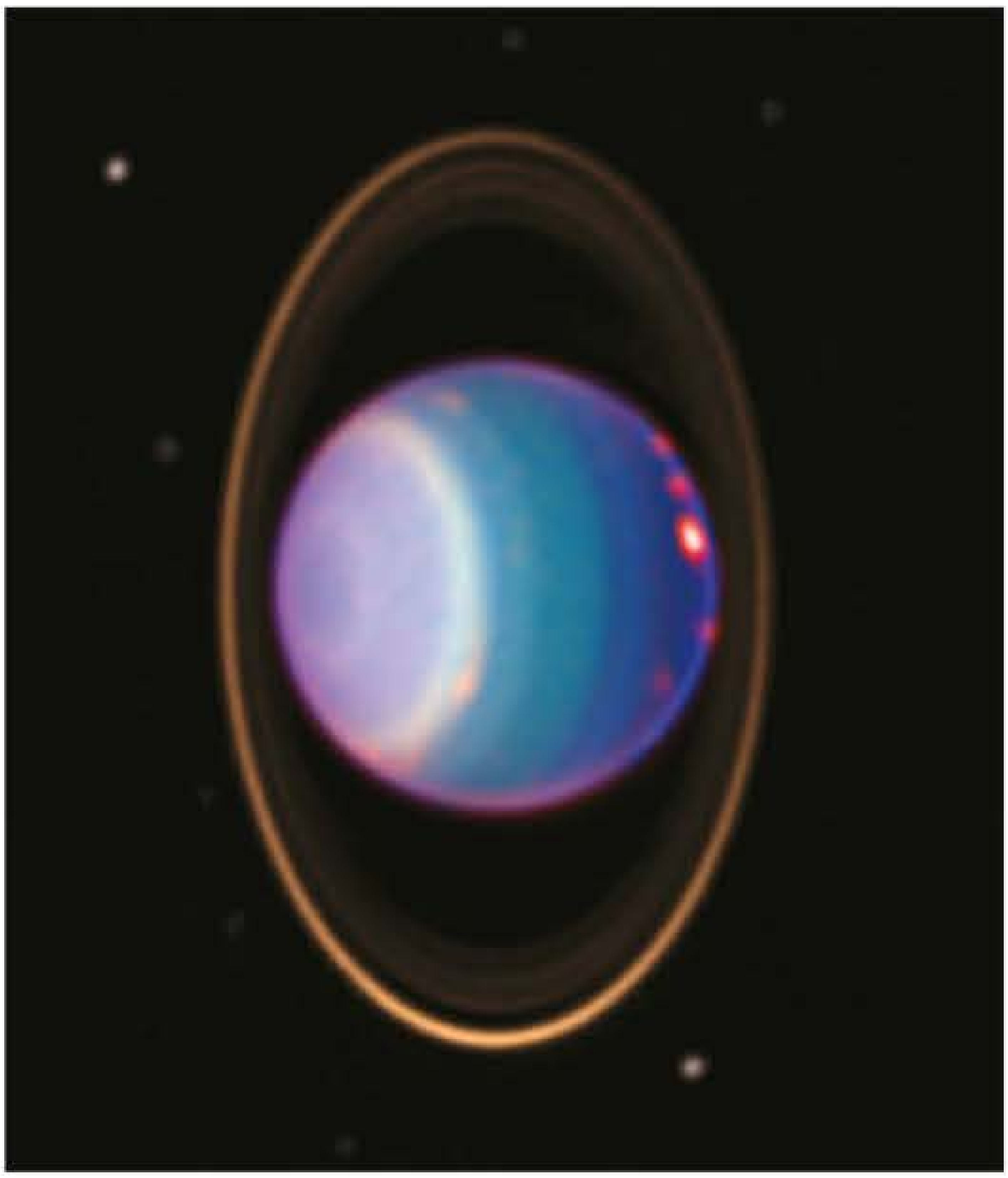
The trouble is we've never seen one of these impacts first hand, and we can't invent a time machine to go back to the early Solar System to check the hypothesis. Instead, researchers are using supercomputers to simulate these sorts of collisions and get to the bottom of what might have happened to Uranus. "We have millions of particles that we put down in our computer and we tell the computer simulation how those particles behave," says Kegerreis, who is part of a project using the technique, called smoothed-particle hydrodynamics, to investigate the giant planet. The researchers input information about how gravity works, what pressure the materials would be under, their density and temperature. "And then we just let those particles smash into each other and evolve the physics as the simulation does," says Kegerreis, "and see where they go."

The latest simulations, presented in a talk at the American Geophysical Union's annual conference last year, show that the impactor could have been an object twice the size of Earth. The object - likely a protoplanet left over from the formation of the Solar System - striking a grazing blow on Uranus would have been enough to knock it off-kilter, but not so violent as to make it lose the atmosphere that we still see surrounding the planet today.

Another finding from the simulations might explain why Uranus is so cold all of the time: debris from the impactor could have made a thin shell around the planet's ice layer, sealing in the inner heat. Nettelman, who published a paper suggesting the existence of such a 'thermal boundary layer' in 2016, says that this layer "prevents heat flow from escaping the deep interior". But it's too early on to rule out all other options when it comes to what hit Uranus; there's a chance the impactor could have been a smaller object in certain circumstances, for instance. If the planet was already tilted by the time an Earth-sized protoplanet hit it, this could have been enough of an extra push to give it the extreme tilt we see today.

The mass could have been bigger as well. "That would obviously be able to knock it over just as easily," says Kegerreis. "But the bigger you make the impact, the less likely it is for that to exist in terms of what would have been flying around the early

Uranus' moons



> "The bigger you make the impact, the less likely it is for that to exist in terms of what would have been flying around" **Jacob Kegerreis**

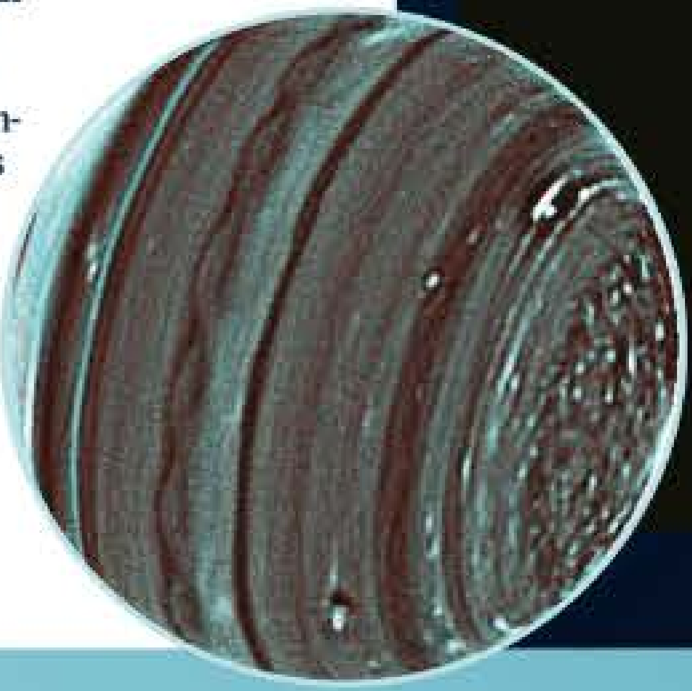
Solar System." There may be remnants of whatever hit Uranus embedded within the planet itself. In the simulations the researchers saw that an impactor could have left lumps of rock inside the planet. These might even be what's causing the ice giant's magnetic field to be tilted strangely and off-centre.

The moons could also provide clues about the impactor. The fact that the major moons of Uranus orbit around the planet's equator suggest that they were either formed from the debris left over after the impact or, if they were already in the process of forming when Uranus was hit, were dragged over when the planet was destabilised.

For his part, Kegerreis says the team is spoilt for choice about what to use the simulations to investigate next. They may look in more detail into what could have caused Uranus' lumpy, lopsided magnetic field, or probe how giant impacts can mix up and change the atmosphere of ice giant planets in general. "We've only just scratched the surface of what we can do with these big simulations," he says.

Above: This false-colour image by Hubble shows bright clouds in the planet's atmosphere in orange

Below: An infrared image of Uranus taken by the Keck II telescope shows storm-like features and clouds



Hubble watches the ice giant's weather

Words by **Meghan Bartels**

IN COOPERATION WITH SPACE.com

If you don't like your local weather, perhaps you would prefer the atmosphere on Uranus or Neptune - and the Hubble Space Telescope has an update on each planet's current conditions.

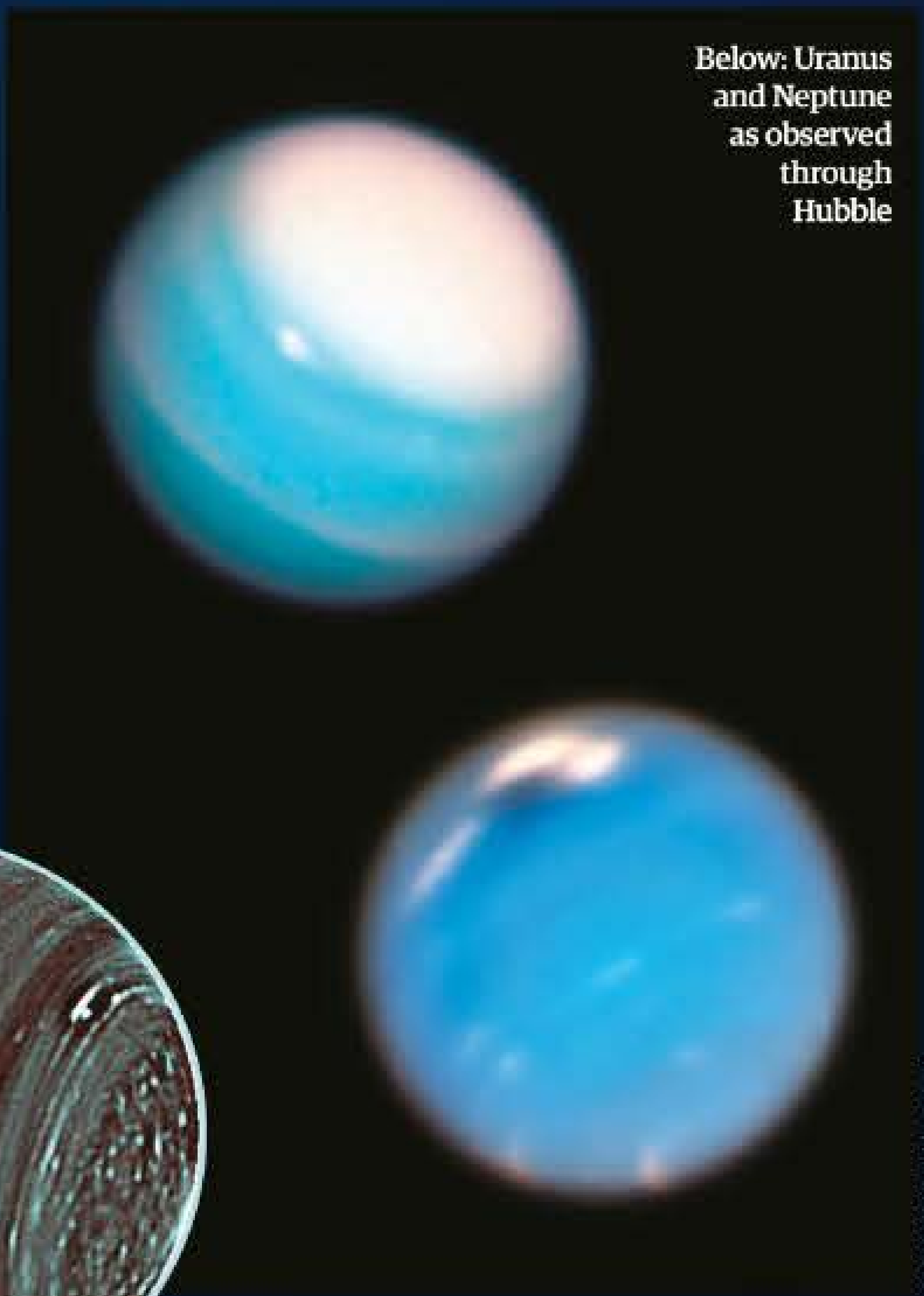
The telescope regularly checks in on the two outer planets to see what's happening in their atmospheres, and last autumn Hubble captured incredible images of clouds on both worlds.

Uranus is currently deep into its summer season, and that shows in the giant, white cloud covering the planet's north pole, which currently points towards the Sun. As scientists have watched the Uranian summer progress - a season on this distant, giant world lasts 21 Earth years - they have seen this massive cloud grow even bigger. The large polar cap is accompanied by a smaller, bright cloud of methane ice.

On Neptune, where seasons last for 41 Earth years, it's winter in the northern hemisphere. That hemisphere is currently sporting a massive dark storm that stretches about 11,000 kilometres (6,800 miles) across.

Scientists aren't sure what phenomenon creates Neptune's dark storms, although the tempests seem to pop up about twice a decade and disperses within about two years. Researchers suspect that the storms creep upwards through the planet's atmosphere, lifting the ingredients of deeper layers of the atmosphere to the top.

Near the dark storm currently on Neptune, Hubble spotted another atmospheric feature: sparkling white 'companion clouds', which scientists have spotted around dark storms in the past. Astronomers suspect that these bright clouds are full of methane ice that's been rapidly pushed upwards and frozen.



Below: Uranus and Neptune as observed through Hubble

© NASA; ESA; Tobias Roesch

This false-colour view of the rings combines images taken by Voyager 2 during its 1986 flyby

> "We really need to figure out if our understanding of Uranus would benefit from a dedicated mission" **Nadine Nettelman**

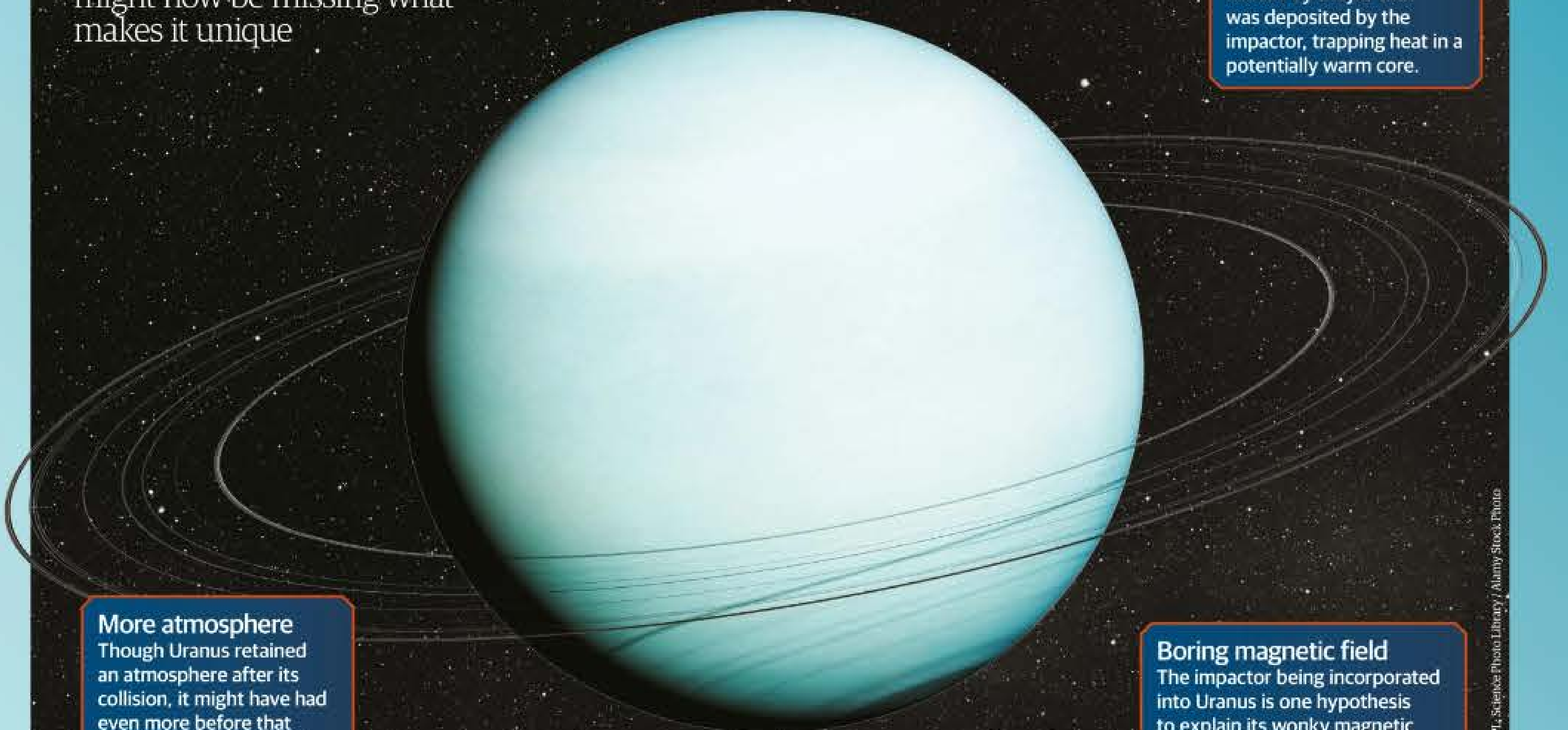
Despite the progress made in recent years, there are still many things left unexplained about Uranus. We still don't know how hot or cold the core of the planet is because we haven't pinned down the details of the possible thermal boundary layer that could be trapping in the heat. We know that Uranus and Neptune have similar magnetic fields, but we don't know why they have such different heat flows. Its icy sibling Neptune is also largely a mystery, having similarly only been visited by the Voyager 2 spacecraft in the summer of 1989. "Compared with pretty much all the other planets, apart from Neptune which is in the same position, an awful lot of the details we really don't know very well," confirms Kegerreis.

Thrusting Uranus and Neptune into the spotlight recently is the fact that a lot of the exoplanets astronomers have been finding outside of the Solar System are similar, at least in size, to the ice giants. In 2014 when Kepler announced the discovery of an incredible 715 new worlds in one go, roughly half of them were similar in size to Neptune. Learning more about the giant planets on our doorstep will make figuring out the details of faraway alien planets much easier.

Some researchers think the only way to really get to grips with Uranus will be a dedicated mission, and in recent years there have been several proposed missions to the ice giant. "I think the time is right, but the planning should not be hasted," says Nettelman. "We really need to figure out if our understanding of Uranus would benefit from a dedicated mission, or maybe more from a combined mission to both Uranus and Neptune." Combining theory and simulations with actual observations will help us get to the bottom of the mysteries hiding underneath Uranus' deceivingly calm exterior. Maybe it'll even teach us something about the whole universe of planets outside our Solar System, too.

What if Uranus hadn't been tipped over?

If it hadn't been hit, the planet might now be missing what makes it unique



Upright tilt
Astronomers expect Uranus started off with a much more slight tilt, if it had one at all. If it hadn't been hit it would have stayed that way.

A warmer exterior
The ice giant's cool appearance could be caused by a layer that was deposited by the impactor, trapping heat in a potentially warm core.

More atmosphere
Though Uranus retained an atmosphere after its collision, it might have had even more before that could have been lost in the violent impact.

Boring magnetic field
The impactor being incorporated into Uranus is one hypothesis to explain its wonky magnetic field. If it hadn't hit, would the magnetic field be less strange?

© NASA/JPL; Science Photo Library / Alamy Stock Photo

POWERBALL® GYROSCOPES

DEVELOP YOUR OWN GRAVITATIONAL FORCES...LIKE TINY SPINNING PLANETS

280 Classic
The Entry One

280 Autostart Classic
The All Round One

Diablo Evo Autostart
The Muscle One

280 Autostart Pro
The Best Selling One

Titan
The Most Powerful One

280 Autostart Fusion
The Amazing One

amazon

★★★★★
Over one thousand
5-star reviews

powerballs.com

A zero gravitational training aid for NASA astronauts, Powerball® develops over 60 times its own weight in gyroscopic resistance and delivers strengthening and rehabilitation for the arms & wrists unlike anything else on *(or off)* this planet.

SUBSCRIBE
to **All About Space** and get a KitSound Cube Portable Bluetooth Speaker*

TINY BUT LOUD

The KitSound Cube Portable Bluetooth Speaker fits into your pocket and has surprising sound thanks to a passive bass radiator.

FEATURES

The speaker is made from solid metal and features 3.5mm line-in connectivity and a play time of six hours.

COLOURS

Choose from three colours: vibrant purple, electric blue or sleek black.

CONNECTION

This speaker also comes with a buddy jack that will enable you to connect to a number of devices for even more volume.

2 FREE POSTERS INSIDE
THE APOLLO PROGRAM // NEBULAE OF THE COSMOS
WIN OREGON 20x80 BINOS
All About Space
NOW FEATURING SPACE.com
50TH ANNIVERSARY
APOLLO 9
THE UNTOLD STORY
UNIVERSE GLITCH
Why does space-time unravel at its edges?
OLDEST SOLAR SYSTEM PUZZLE SOLVED
WHAT HIT URANUS?
REVEALED! The massive force that changed an ice giant forever
MUSK GOES RETRO
INSIDE STARSHIP HOPPER
NASA SCIENTISTS DEBATE
WILL THE JWST EVER LAUNCH?
THE GLITCH AT THE END OF THE UNIVERSE

WHY SUBSCRIBE?

- Brilliant value – save money on the cover price
- You'll never miss an issue
- It's delivered direct to your door

Subscribe now

www.myfavouritemagazines.co.uk/aas/88M

or call 0344 848 2852 & quote AAS88M

PRINT

Six-month subscription to **All About Space** in print, plus a KitSound Cube

£20.50

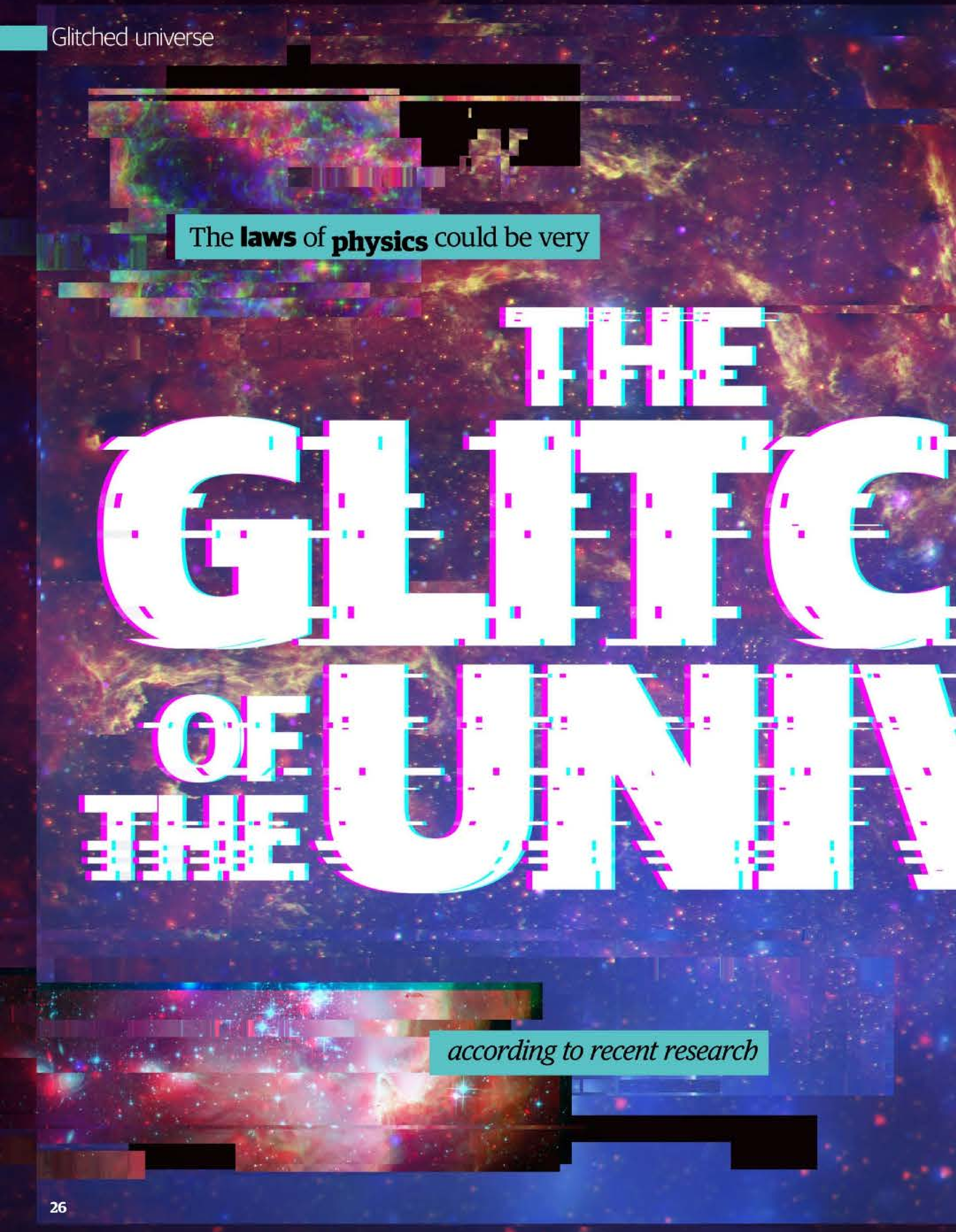
PRINT & DIGITAL

Six-month subscription to **All About Space** in print & digital, plus a KitSound Cube

£23

*Terms and conditions: This offer entitles new UK Direct Debit subscribers to pay just £20.50 every 6 months plus receive a Cube Speaker. Gift is only available for new UK subscribers. Gift is subject to availability. Please allow up to 60 days for the delivery of your gift. In the event of stocks being exhausted we reserve the right to replace with items of similar value. Prices and savings quoted are compared to buying full-priced print issues. You will receive 13 issues in a year. Your subscription is for the minimum term specified. You can write to us or call us to cancel your subscription within 14 days of purchase. Payment is non-refundable after the 14-day cancellation period unless exceptional circumstances apply. Your statutory rights are not affected. Prices correct at point of print and subject to change. UK calls will cost the same as other standard fixed-line numbers (starting 01 or 02) or as included as part of any inclusive or free minutes allowances (if offered by your phone tariff). For full terms and conditions please visit: www.bit.ly/magterms. Offer ends 28 March 2019.

Direct Debit Originator's reference 768195



The **laws** of **physics** could be very

THE GLITC OF THE UNIV

according to recent research

different in both space and time,

H AT THE END VERSE

Reported by Abigail Beall

© NASA/JPL

Right: The European Southern Observatory has commissioned a brand-new, ultra-stable and precise spectrograph on its Very Large Telescope

Bottom: An artist's impression of one of the oldest quasars

When it comes to the laws of physics, you could be forgiven for thinking there are rules which apply no matter where you are in time or space. After all, this is what we are taught. But everything you think you know about the universe could be wrong, thanks to a glitch.

The laws of physics may be different across the universe, in both space and time. This is according to a theory that has been in testing for the past 21 years which, if proven correct, could rewrite the laws of physics altogether. There is a set of numbers known as the fundamental constants which play a vital role in physics in determining how particles interact with each other.

Quantum electrodynamics, or QED, describes how the electromagnetic force works on the quantum level. In QED there is an important number called alpha. It governs how light particles interact with electrically charged particles, like electrons, muons and tau. Alpha, which is also called the fine-structure constant, is calculated using the speed of light, Planck's constant and the charge of an electron. It can be measured experimentally and has been measured to a strong degree of precision on Earth. One divided by alpha has been measured to be 137.035999074, with an experimental uncertainty of just 0.000000044. However, nobody knows exactly why alpha is the number it is, and there are increasing hints the constant might not be so constant throughout the universe.

Alpha can be measured by studying light coming from distant galaxies. When light hits an atom it is only absorbed if the energy is equivalent to the energy needed to shift the electrons up an energy level. These electrons will be unstable in this new energy level, so will fall down again and release a photon with a wavelength equivalent to the light that was absorbed. Alpha determines how electrons interact with the nucleus of an atom because it changes how strong the attraction is. If alpha changed, the wavelength of light absorbed by atoms would also change. Therefore, by studying light emitted from the gas near distant objects, like quasars, scientists can study alpha.

In 1998 a team led by Professor John Webb at the University of New South Wales in Sydney, Australia, became interested in studying alpha in different galaxies. "In 1998 I started working with Webb at UNSW as an Honours student, finishing up my undergraduate degree in physics," says Michael Murphy, who is now a professor of astronomy at Swinburne University in Melbourne. "John had just started a collaboration with Victor Flambaum and Vladimir Dzuba in the physics department there to try to measure possible variations in alpha using quasar spectra."

Flambaum and Dzuba were atomic physics experts, while Webb was an expert in studying quasar absorption lines. "It was a great match of expertise, and soon they had their first results," says Murphy. The results were interesting. They showed that between 12 and 6 billion years ago, alpha had increased by an average of six parts in a million. This was not enough to significantly affect physics at that time, but it was enough to keep the researchers interested. "It was my job to start trying to understand what might be wrong with these results – the less-than-glamorous but hugely important hunt for systematic errors," says Murphy.

After finishing his Honours, Murphy embarked on a PhD with Webb on the same topic. This time he focused on trying to do the measurements as well as trying to understand how they might be affected by systematics.

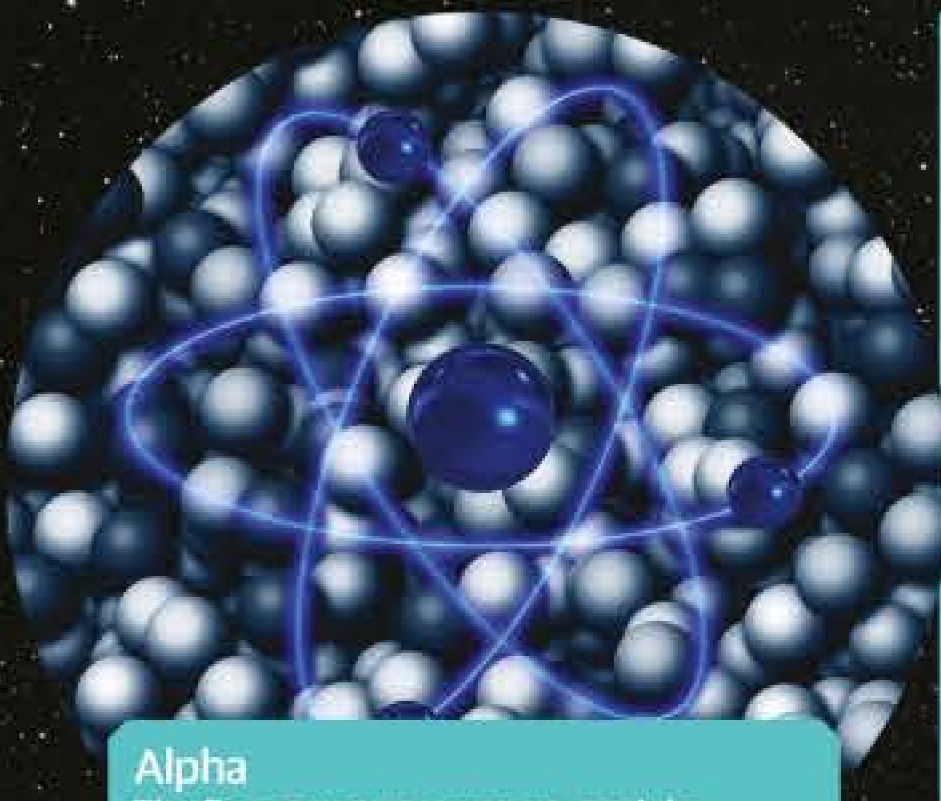
Years later, Murphy published a study in 2010 working alongside Webb, Flambaum and Professor Bob Carswell at the University of Cambridge. The study looked at absorption spectra from quasars in around 300 different galaxies. This time, the results were more convincing. They suggested that alpha varies by about one part in 100,000. On top of this, it seemed the number varied from one side of the universe to the other – as we look at it.

If alpha were to be different across the universe it would have huge implications for the laws of physics. "It would be akin to observing that the advance in Mercury's perihelion didn't quite match Newton's theory of gravity," says Murphy. "In that case a completely new theory with a completely different concept of how gravity worked was required to explain it."

Observing a variation in alpha, or another fundamental constant, would be a sign that the

Space-time's numbers

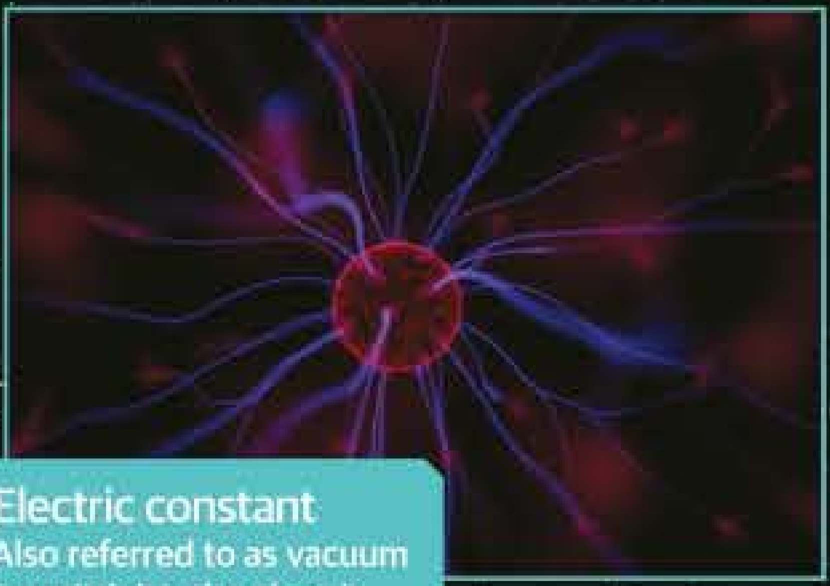
The six fundamental constants that shape the universe and allow life to exist on Earth



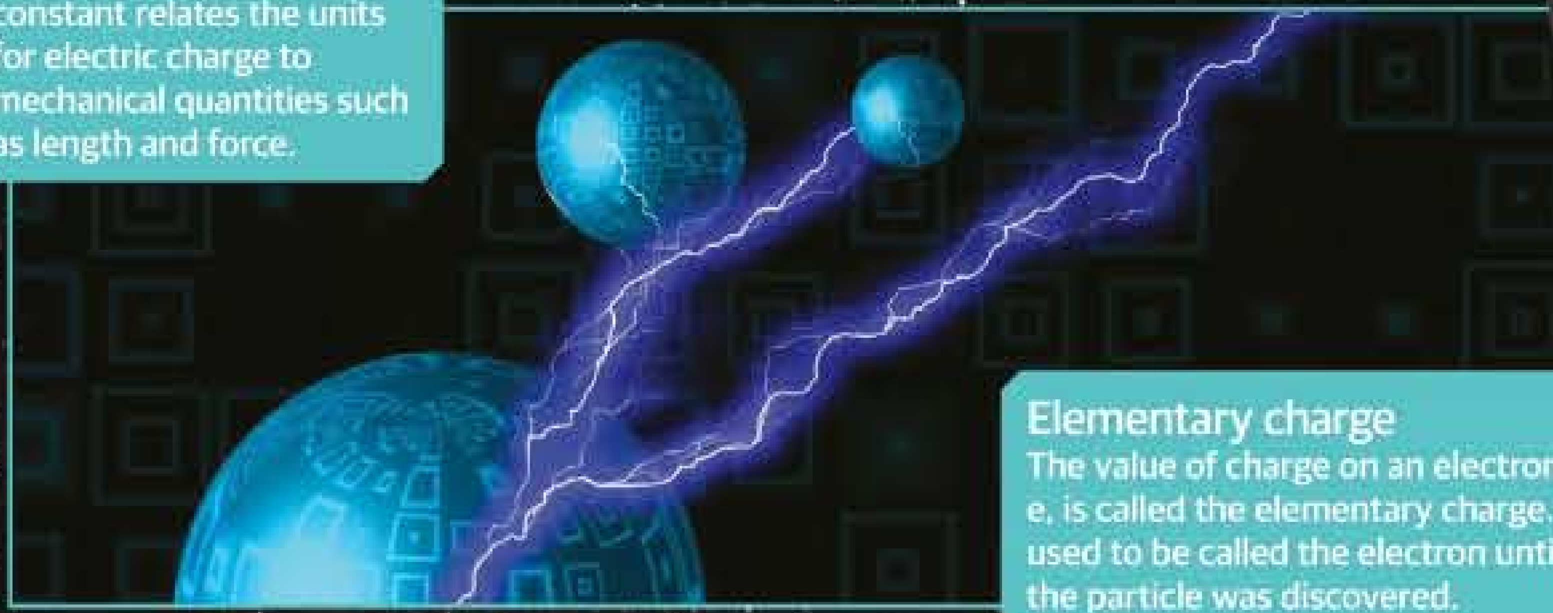
Alpha
The fine-structure constant, or alpha, determines the strength of electromagnetic interactions – like the bonds between electrons and other particles.

Gravitational constant
This constant, G, defines the level of attraction between two objects. For example, it determines why the Moon orbits Earth and why Earth orbits the Sun.

Planck's constant
This relates the energy carried by a photon to its frequency. It is important in quantum mechanics and forms the basis of how we have measured the kilogram.



Electric constant
Also referred to as vacuum permittivity, the electric constant relates the units for electric charge to mechanical quantities such as length and force.



Elementary charge
The value of charge on an electron, e, is called the elementary charge. It used to be called the electron until the particle was discovered.

Speed of light
The speed of light in a vacuum, c, is the maximum speed at which all conventional matter can travel.

What if these numbers changed?

Fine-structure constant
If alpha were larger, nuclear fusion within stars would not be able to occur, meaning carbon, the element on which life is based, could not be produced.

Gravitational constant
If it were smaller, planets might not orbit around stars, and whole galaxies might fall apart. If G were larger we might not be able to survive on Earth.

Elementary charge
If the elementary charge of particles were to change, we'd see alterations on a more subatomic level - especially in how the way charged particles interact with each other.

Planck's constant
If Planck's constant were to increase greatly it could mean atoms cease to exist altogether, as electrons could be freed from their nuclei very readily.

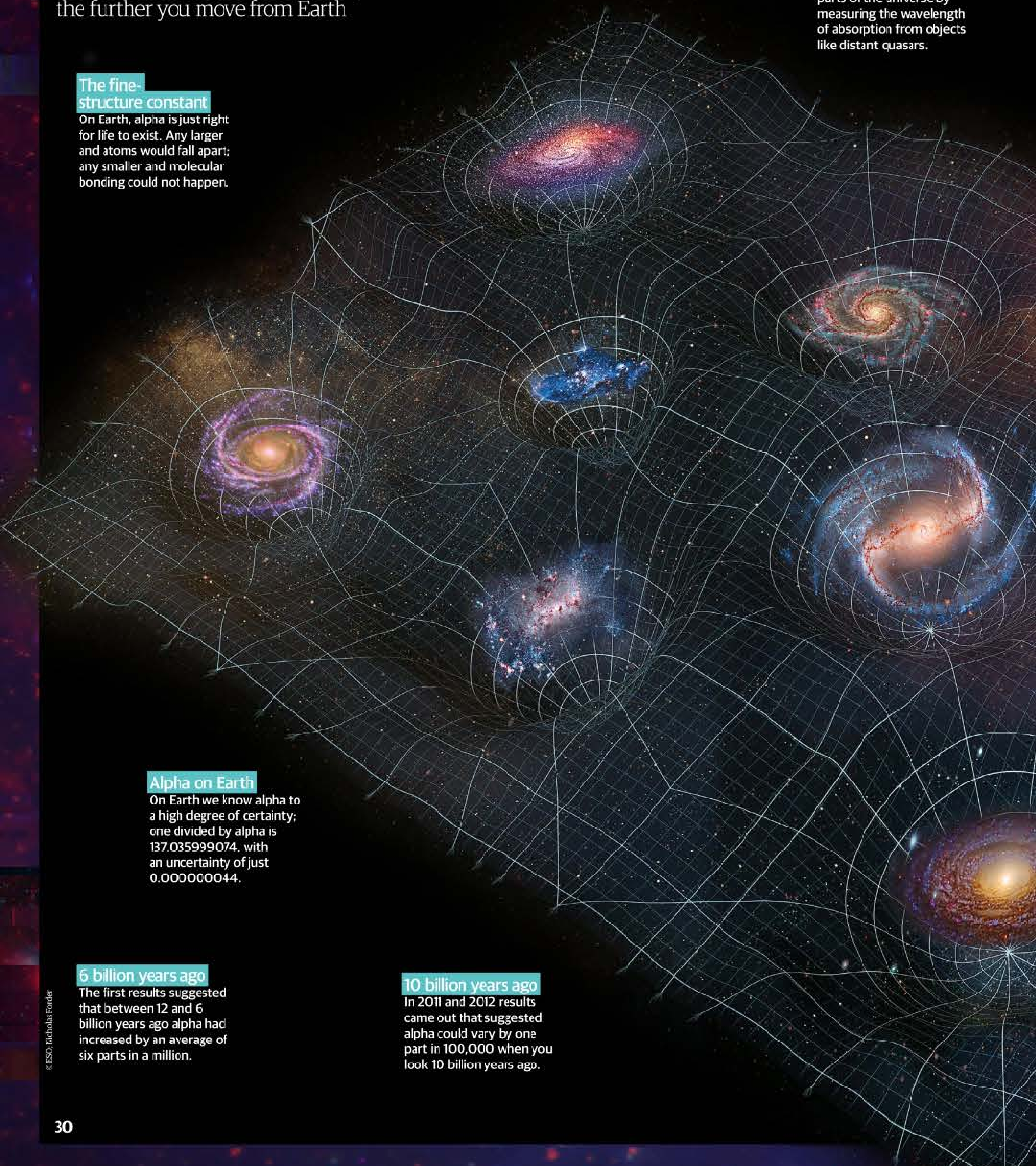
The speed of light
If the speed of light changes across the universe it might mean our estimates about the size and even the age of the universe could be wrong.

Electric constant
If the electric constant were greater the force between two separate electric charges would be weaker. This would have a huge impact on electromagnetism as we know it.

© NASA/ESA/ESO; Urnismoobjetivo

Universe's glitch

The cosmos might look completely different the further you move from Earth



Measuring alpha

We can study the value of alpha at different parts of the universe by measuring the wavelength of absorption from objects like distant quasars.

The fine-structure constant

On Earth, alpha is just right for life to exist. Any larger and atoms would fall apart; any smaller and molecular bonding could not happen.

Alpha on Earth

On Earth we know alpha to a high degree of certainty; one divided by alpha is 137.035999074, with an uncertainty of just 0.000000044.

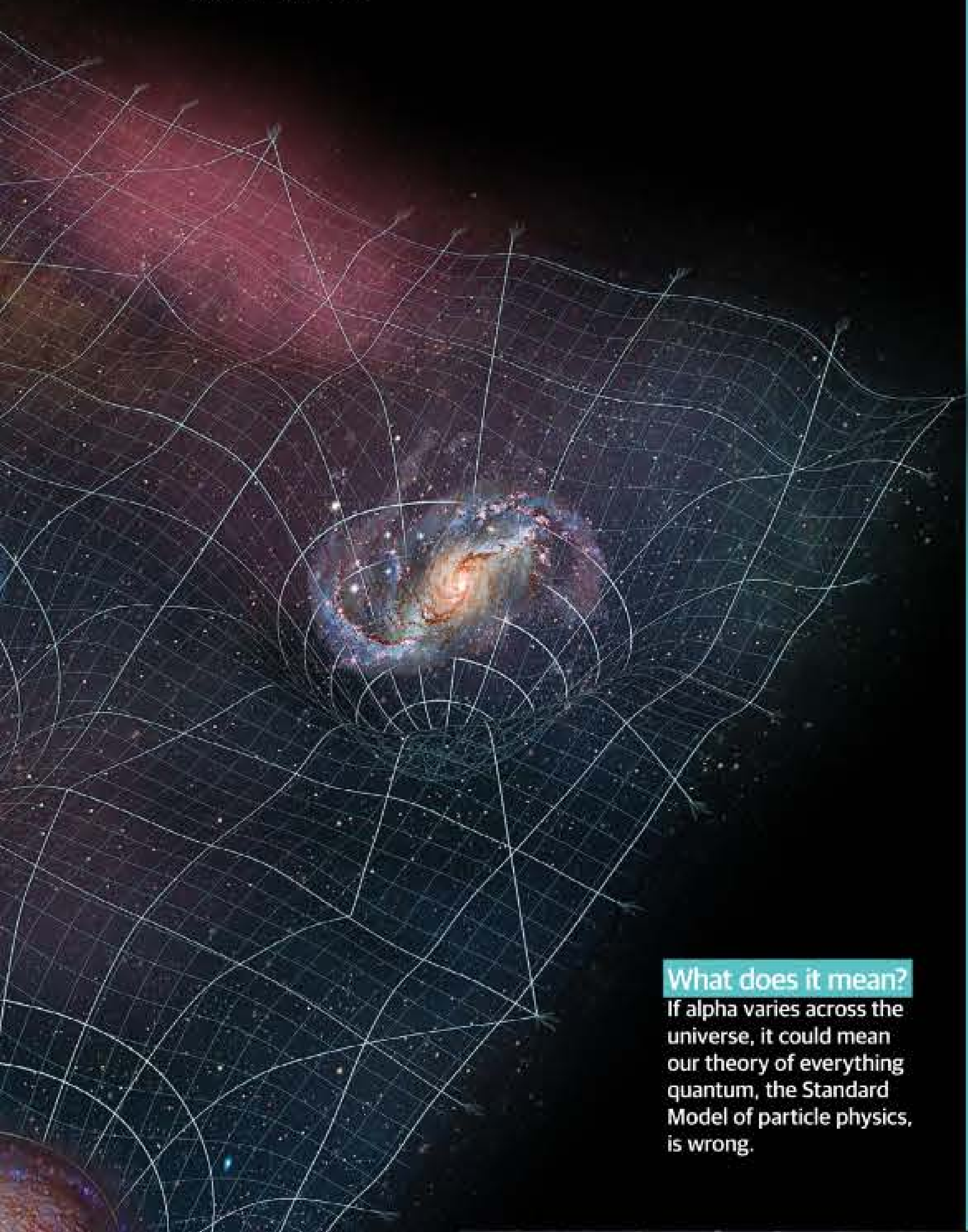
6 billion years ago

The first results suggested that between 12 and 6 billion years ago alpha had increased by an average of six parts in a million.

10 billion years ago

In 2011 and 2012 results came out that suggested alpha could vary by one part in 100,000 when you look 10 billion years ago.

© ESO; Nicholas Forder



Almost 14 billion years ago
Looking back this far, we are studying the very first light in the universe. The further away we look the more hints there are that alpha is different.

300 quasars
In 2010 a study looking at 300 distant quasars showed hints that alpha varies across the universe along a specific axis.

What does it mean?
If alpha varies across the universe, it could mean our theory of everything quantum, the Standard Model of particle physics, is wrong.

> "Observing a variation would be a hugely important guide to what any new theory has to explain" **Michael Murphy**

Standard Model of particle physics, our theory of everything except gravity, is fundamentally incorrect. "It would mean we'd have to come up with a new theory altogether, possibly one with completely different concepts of how our universe works at a fundamental level," says Murphy.

Much of theoretical physics research today focuses on trying to understand what the next most fundamental theory of the universe is, with many physicists certain the Standard Model is not complete. For example, the Standard Model does not explain quantum gravity, and it is also incompatible with Einstein's theories of relativity.

"Observing a variation in alpha would be a hugely important guide to what any new theory has to explain," says Murphy. "Just like Mercury's anomalous perihelion advance helped guide Einstein's general theory of relativity." If we discovered that the fine-structure constant varied throughout the universe, this would also help explain the mystery of why alpha is perfect for life.

Mysteriously, alpha is just right for life as we know it to exist. In other words, if alpha changed, the universe would look totally different. "If the fundamental constants were significantly different, any life as we know it could not appear," says Flambaum, who has worked on experiments to study alpha since Webb's experiments in 1998.

If alpha was much smaller, the attraction between charged particles would be weaker, and molecular bonds, also known as covalent bonds, which rely on atoms sharing electrons, would fall apart at lower temperatures. This would have drastic effects on a huge number of processes necessary for life - molecular bonds are crucial for forming water, carbon dioxide and methane, for example.

On the other hand, if alpha was bigger, protons would repel each other so strongly that the nuclei inside atoms could not stick together. If it were even larger than this, nuclear fusion within stars would not be able to occur, meaning carbon, the element on which life is based, could not be produced.

Luckily for us, alpha is just right. But nobody knows why. If alpha changes across the universe,

Below: The Milky Way stretches above the Paranal observatory, home to the Very Large Telescope

Why doesn't the universe make sense?

Astrophysicists reveal what could be causing the glitch

If alpha were not a constant, what would this mean for our understanding of the universe?
It would be akin to observing that the advance in Mercury's perihelion didn't quite match Newton's theory of gravity. In that case a completely new theory was required.
Professor Michael Murphy, Swinburne University

Where are we at now in terms of understanding if alpha is the same everywhere in the universe?
Astrophysical measurements by the John Webb group based on the quasar absorption spectra of ions indicate variation of alpha in space. This group made measurements based on over 300 absorption systems across the skies using original methods and made numerous tests of the results. Other groups used small samples of data and do not see the variation yet. All new data is based on the same Many-Multiplet method. There are no direct contradictions, but Webb group results are considered to be unconfirmed.
Professor Victor Flambaum, UNSW

Why are the fundamental constants so important to physics?
A fundamental constant can be defined as being a parameter for which the value doesn't arise from the theory. They are quantities that can only be measured. Testing their constancy is in itself a test of the theories we use. They allow us to test the domain of their validity and if their constancy doesn't hold true new physics should arise. If we detect a variation, either in time or by local environment conditions, then we would expect that they impact our current interpretation of the universe.
Ana Catarina Leite, PhD student at the Instituto de Astrofísica e Ciências do Espaço

Do you think, given all evidence, alpha varies across the universe?
The answer is no. In 1998 a group of Australian astronomers studying quasar absorption system spectra claimed a detection of a variation in alpha. However, more recently the same researchers performed a recalculation of systematic errors using new techniques and showed that there's no compelling evidence for any variation in alpha from quasar data. Furthermore, it follows from analyses with data from the Cosmic Microwave Background and the abundances of light elements such as helium and deuterium that the value of alpha in the early universe is the same as its present value. On the other hand, experiments with atomic clocks rule out possible present time variations of alpha with great precision. Finally, data from the natural nuclear reactor that operated 1,800 million years ago at the present site of the Oklo mine in Gabon also discards a possible time variation of alpha. Other analyses were also performed using data from type Ia supernovae, galaxy clusters and white dwarfs and no evidence for a variation in alpha was found.
Susana Landau, National Scientific and Technical Research Council, Buenos Aires

however, then it makes sense that we appeared in the part where it is ideal for life to exist.

"Variation of the fundamental constants in space provides a natural explanation: we just appeared in the area of the universe where the fundamental constants are good for us," says Flambaum. "[The] universe is very large. Therefore the variation inside the visible universe may be small and hard to detect," he says.

In 2011 and 2012 results came out that suggested alpha could vary across the sky. Researchers used the Keck telescope in Hawaii and the Very Large Telescope in Chile. They found alpha could vary by one part in 100,000 when you look 10 billion years apart. Flambaum says the most recent measurements indicate a variation of alpha throughout space, but Murphy is not so certain.

Between 2013 and 2015 Murphy and his colleagues in Europe and India identified some problems with the spectra recorded by the largest optical telescopes on Earth that had been used to study the quasars. "The spectrographs on those telescopes were slightly distorting the spectra in just such a way that could mimic the signal of a varying alpha," says Murphy. However, the team cannot say for sure that this explains all the previous results because, to measure this effect, they had to use historical observations of asteroids and stars like our Sun.

"There are not so many of these that are useful, so we're only able to sketch out a rough history of these distortions through the same decade or two when the quasar observations were being taken," says Murphy. "Still, to my mind, this really undermines any confidence one could have in the early quasar results."

In 2017 Webb, along with Vincent Dumont of the University of California, Berkeley, refuted these results. They claimed the data analysis was flawed and applied only to a subset of the results derived from the Very Large Telescope, not the original results. More recent work completed by Murphy found no evidence for variations in alpha, down to just a few parts per million precision. However, again, he says they cannot yet rule out the suggestion it changes across the sky.

The debate may be answered once and for all as the European Southern Observatory has just commissioned a brand-new, ultra-stable and precise spectrograph on their Very Large Telescope, called ESPRESSO (Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations). "This is the perfect machine for recording spectra of quasars to measure alpha," says Murphy, who is a member of the ESPRESSO science team. "It won't have any of the distortions that plagued the more 'general-purpose' spectrographs we had used before."

ESPRESSO has already started gathering data, and results could be produced in the next few years. "We already have some data on quasars and, I must say, it's the best data I've seen by a long way," says Murphy. Yet the team will have to wait until they have analysed thousands of measurements before ruling anything out - whatever the outcome, it's sure to improve our understanding of the cosmos.

> "If the fundamental constants were significantly different, any life as we know it could not appear" **Victor Flambaum**

Below: A very distant quasar powered by a black hole with a mass 2 billion-times that of the Sun

© ESO/CAS; UNSW

Planet Earth Education

Planet Earth Education

And Mobile Stars Planetarium

Why study Astronomy?
How does Astronomy affect our everyday life?

- **The Sun provides our energy to live and is used for timekeeping.**
- **The Moon causes eclipses whilst its phasing determines the date for Easter Sunday.**
- **Constellations can be used for navigation.**
- **Astronomy is one of the oldest sciences.**

Planet Earth Education is one of the UK's most popular and longest serving providers of distance learning Astronomy courses. We pride ourselves on being accessible and flexible, offering attractively priced courses of the highest standards. Students may choose from five separate Astronomy courses, suitable for complete beginner through to GCSE and first-year university standard.

Planet Earth Education's courses may be started at any time of the year with students able to work at their own pace without deadlines. Each submitted assignment receives personal feedback from their tutor and as there are no classes to attend, students may study from the comfort of their own home.

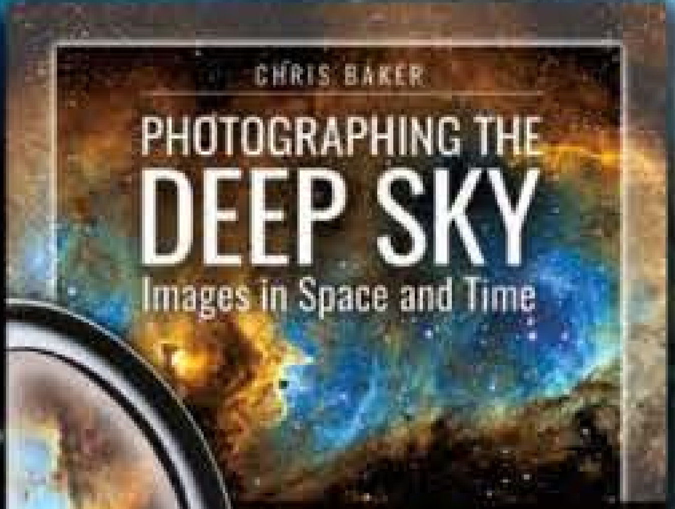
Of paramount importance to us is the one-to-one contact students have with their tutor, who is readily available even outside of office hours. Our popularity has grown over several years with home educators using our courses for the education of their own children, many of whom have obtained recognised science qualifications at GCSE Astronomy level. With each successfully completed Planet Earth Education course, students receive a certificate.

Visit our website for a complete syllabus of each available course, along with all the necessary enrolment information.

Courses available for enrolment all year round.

☎ 0161 653 9092 www.planeteartheducation.co.uk

WHITE OWL BOOKS



ISBN: 9781526715531

~~£25.00~~

WHITE OWL BOOKS
01226 734222
OR ORDER ONLINE
www.whiteowlbooks.co.uk

PHOTOGRAPHING THE DEEP SKY

CHRIS BAKER

Space and time and the evolution of the Earth are interwoven using beautiful images of the Deep Sky in this accessible and richly illustrated book.

In this very personal account Chris gives guidance on astro-photography and how to get started.

With a concise, clear discussion of the background astronomical science, this is above all, a book to celebrate the beauty and fascination of space.

NOW £20.00 USE CODE: PDS01

INTRODUCING THE STARSHIP HOPPER

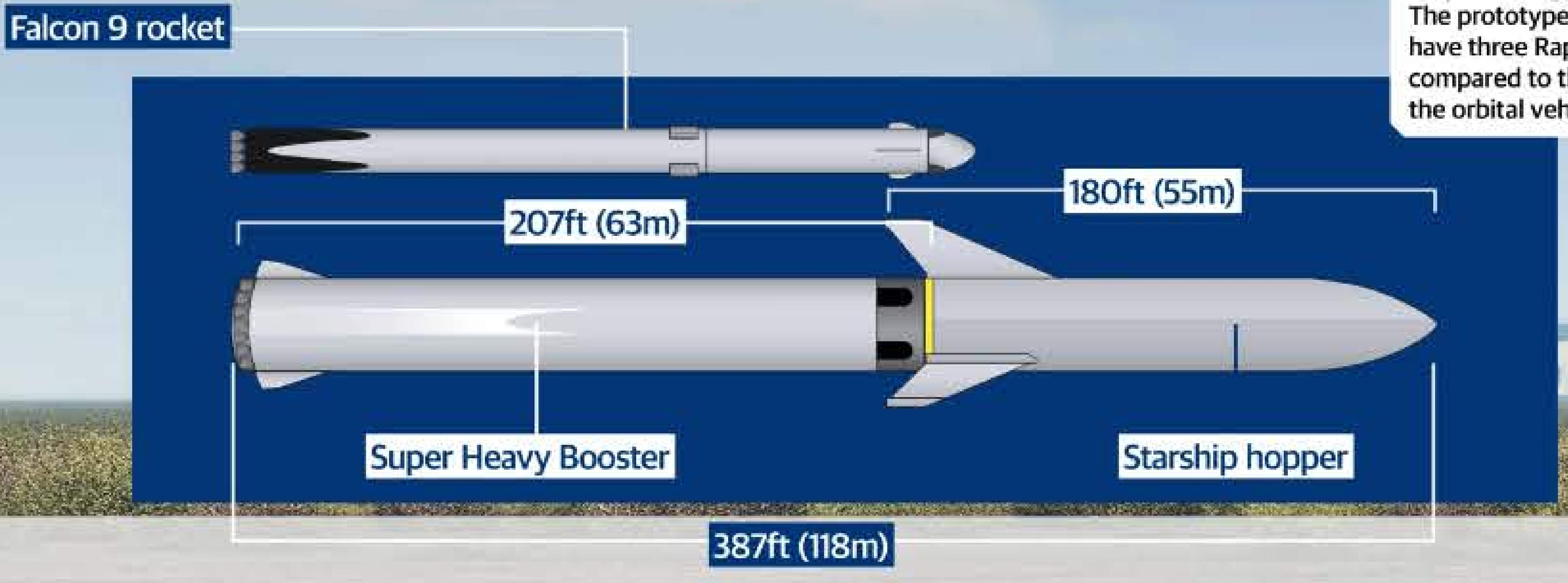
Elon Musk has teased the world with sneak peeks of what the spaceship to take humans to Mars could look like

Reported by Lee Cavendish

SpaceX continues to amaze in popularising space exploration. Not only is it doing fantastic work in reaching and exploring space, shown by its efforts to transport supplies and astronauts to the International Space Station, it also flaunts retro exhibitions that capture the interest of people worldwide. Recently, Elon Musk – the CEO of SpaceX – has released images and information on what he calls the 'Starship' Hopper test rocket. The prototype of this vehicle has recently been constructed in a project that will hopefully be used to colonise Mars.

Anyone who follows Musk will know that he is a keen advocate of going to Mars, and with scientists and engineers urging everyone to get behind an exploration mission that can take us to a whole new frontier, it is now becoming more of a reality than a dream. Starship, formerly known as the Big Falcon Rocket (BFR), could be the rocket to undertake this important task. In order for this rocket to be successful there are many things to take into account, and a lot of power needs to be exerted by the rocket. This is not just another 384,400-kilometre (238,855-mile) mission to the Moon. This is going to be a journey more than 140-times longer. This means that there needs to be enough food, supplies and protection from the harmful radiation of space in order to survive this journey, and even then there's the question of how much fuel is needed to break free of Earth's gravity and make it Mars.

These are the reasons why a voyage to Mars is a struggle. But nothing good ever comes easy. SpaceX has shown extremely promising signs of improved space exploration with the introduction of reusable rockets, and now Musk has released the first images of the Starship prototype rocket that will soon undergo short 'hopping' excursions to test its feasibility. These vertical takeoff and landing (VTOL) tests will hover around five kilometres (three miles) above the ground before landing back on Earth. The rocket towers at a height of about 39 metres (128 feet) and has a diameter of nine metres (30 feet),



Raptor engines
The prototype Hopper will have three Raptor engines, compared to the seven for the orbital vehicle.

> "Starship will be just one part of the entire project – SpaceX is also developing the Super Heavy rocket which will give Starship the initial thrust"

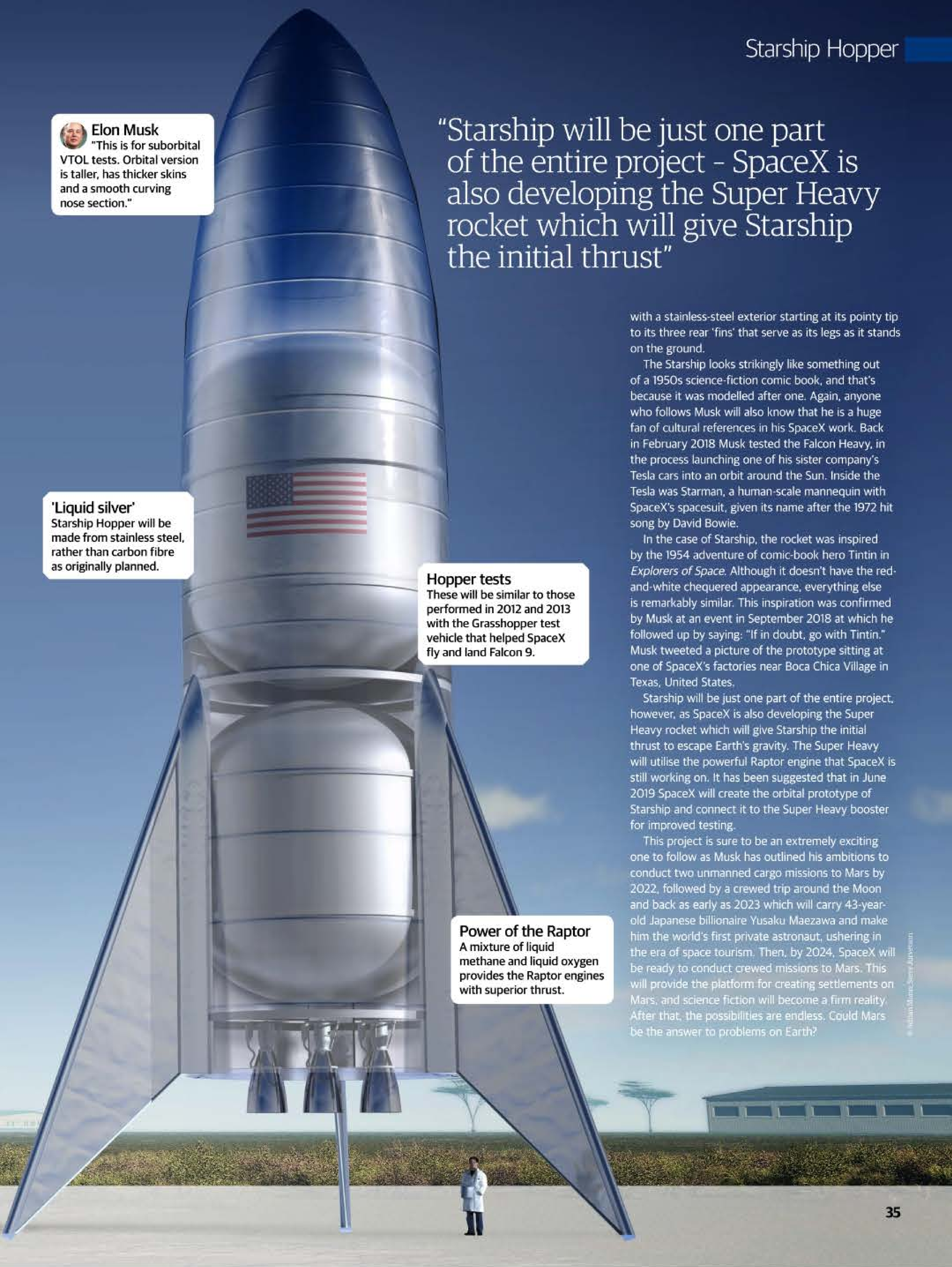
with a stainless-steel exterior starting at its pointy tip to its three rear 'fins' that serve as its legs as it stands on the ground.

The Starship looks strikingly like something out of a 1950s science-fiction comic book, and that's because it was modelled after one. Again, anyone who follows Musk will also know that he is a huge fan of cultural references in his SpaceX work. Back in February 2018 Musk tested the Falcon Heavy, in the process launching one of his sister company's Tesla cars into an orbit around the Sun. Inside the Tesla was Starman, a human-scale mannequin with SpaceX's spacesuit, given its name after the 1972 hit song by David Bowie.

In the case of Starship, the rocket was inspired by the 1954 adventure of comic-book hero Tintin in *Explorers of Space*. Although it doesn't have the red-and-white chequered appearance, everything else is remarkably similar. This inspiration was confirmed by Musk at an event in September 2018 at which he followed up by saying: "If in doubt, go with Tintin." Musk tweeted a picture of the prototype sitting at one of SpaceX's factories near Boca Chica Village in Texas, United States.

Starship will be just one part of the entire project, however, as SpaceX is also developing the Super Heavy rocket which will give Starship the initial thrust to escape Earth's gravity. The Super Heavy will utilise the powerful Raptor engine that SpaceX is still working on. It has been suggested that in June 2019 SpaceX will create the orbital prototype of Starship and connect it to the Super Heavy booster for improved testing.

This project is sure to be an extremely exciting one to follow as Musk has outlined his ambitions to conduct two unmanned cargo missions to Mars by 2022, followed by a crewed trip around the Moon and back as early as 2023 which will carry 43-year-old Japanese billionaire Yusaku Maezawa and make him the world's first private astronaut, ushering in the era of space tourism. Then, by 2024, SpaceX will be ready to conduct crewed missions to Mars. This will provide the platform for creating settlements on Mars, and science fiction will become a firm reality. After that, the possibilities are endless. Could Mars be the answer to problems on Earth?

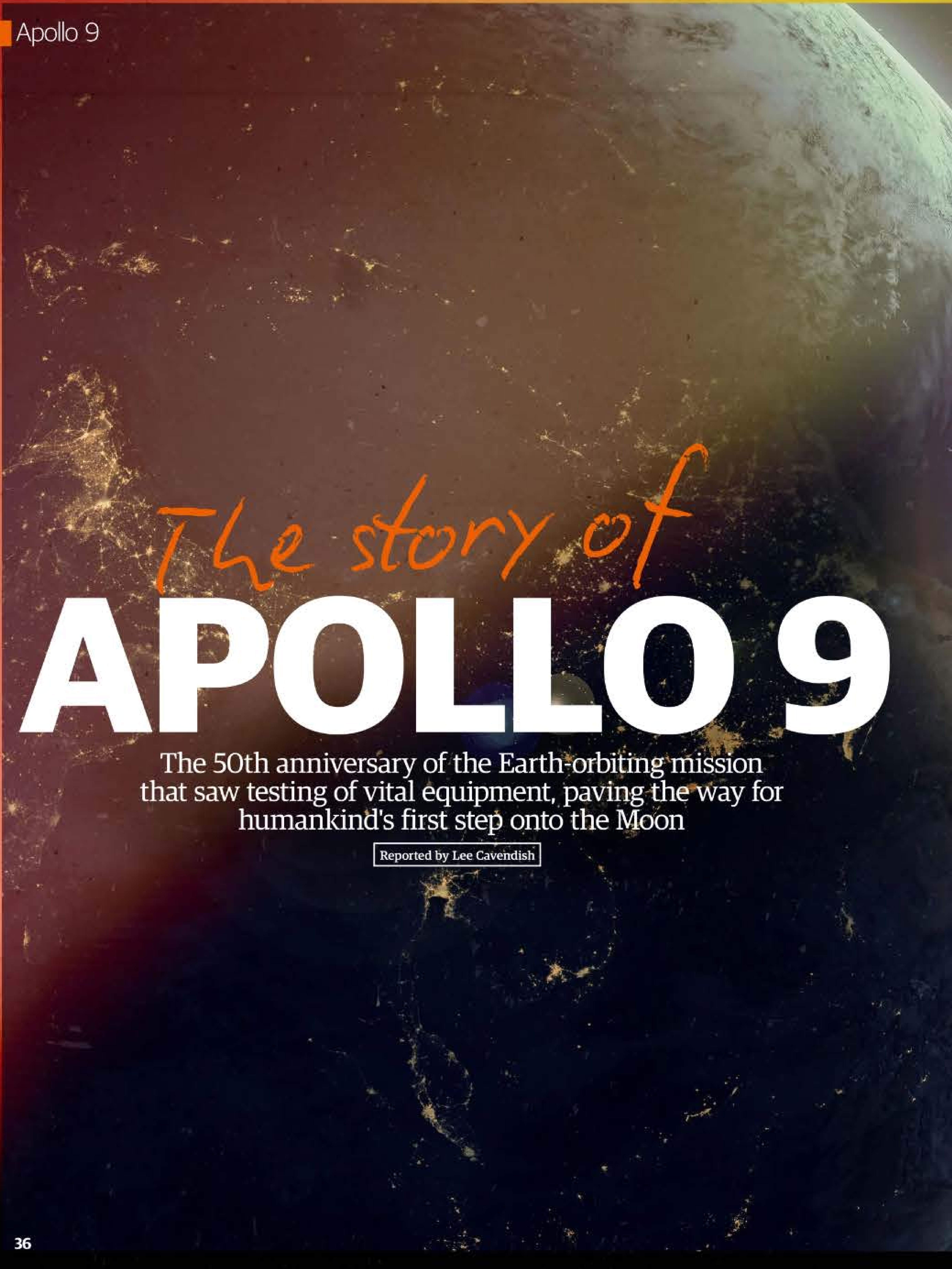


Elon Musk
"This is for suborbital VTOL tests. Orbital version is taller, has thicker skins and a smooth curving nose section."

'Liquid silver'
Starship Hopper will be made from stainless steel, rather than carbon fibre as originally planned.

Hopper tests
These will be similar to those performed in 2012 and 2013 with the Grasshopper test vehicle that helped SpaceX fly and land Falcon 9.

Power of the Raptor
A mixture of liquid methane and liquid oxygen provides the Raptor engines with superior thrust.



The story of APOLLO 9

The 50th anniversary of the Earth-orbiting mission that saw testing of vital equipment, paving the way for humankind's first step onto the Moon

Reported by Lee Cavendish

© Martin Jones / Alamy Stock Photo

The Apollo program paved the way for human space exploration and inspired a generation of future astronauts, scientists and engineers. Apollo 11, the mission that saw Neil Armstrong and Buzz Aldrin step foot on the Moon, wasn't possible without the ten other missions before it. Here **All About Space** celebrates the 50th anniversary of the Apollo 9 mission that saw James A. McDivitt, David R. Scott and Russell "Rusty" Schweickart conduct the first tests of the crewed Lunar Module (LM) and Command Service Module (CSM) along with the portable life-support systems that would be used when exploring the Moon.

On 3 March 1969 these three astronauts strapped themselves in for the ride of their lives, sitting aboard a Saturn V rocket at NASA's John F. Kennedy Space Center in Florida, United States. This mission was only the second crewed mission to launch on a Saturn V rocket, and the third crewed mission in the United States' Apollo program. For the next 241 hours and 54 seconds the Apollo 9 crew would experience the wonders of space while performing their duties as professionals to ensure for a successful trip. But what if they weren't even supposed to be there?

This was almost the case, as McDivitt, Scott and Schweickart were all actually supposed to be on the earlier Apollo 8 mission - the mission that circled the Earth in December 1968. "Those were very complicated times and the mission shifted all over. We were actually the backup crew for the first Apollo missions, including Apollo 7, but we were also going to pick up the Lunar Module and be the first to fly it," Schweickart tells **All About Space**. "Then we were shifted off the backup crew and [Walter] Wally Schirra's team took our places for the first Apollo mission, with Gus Grissom, Roger Chaffee and Ed White the appointed first-choice crew. We moved into a totally different mission, but we were going to fly the Lunar Module. Then that didn't work and Frank Borman proposed moving his flight."

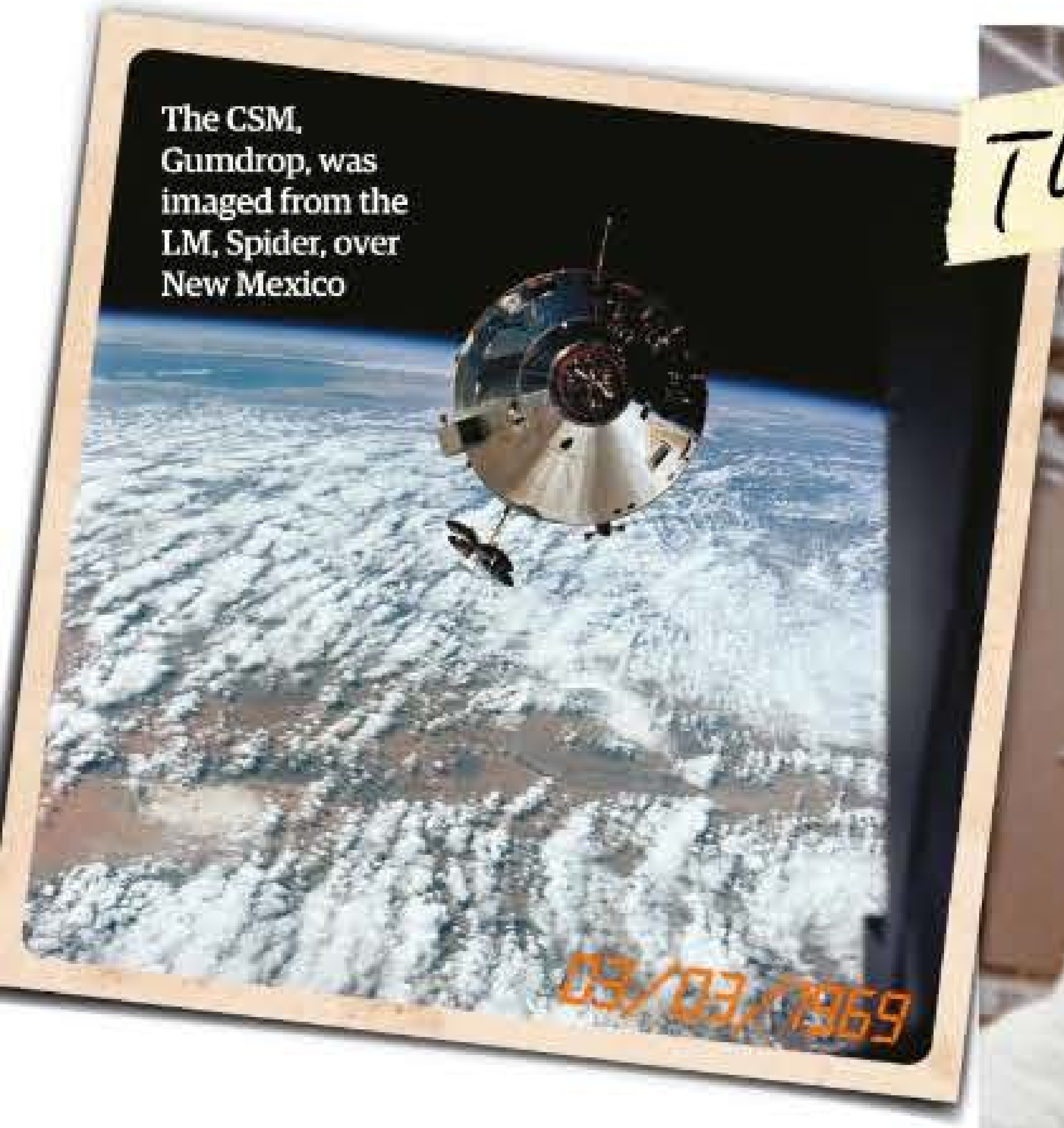
Each prime crew had a backup crew who would fly as the prime crew three missions later, and it was this rule that led to Armstrong and his crew flying as the prime crew on Apollo 11. But they had to wait. As for Apollo 9, it had to reach space and test the technologies that NASA had been improving in its laboratories. Each crew member was selected from the astronaut group of either 1962 or 1963. The commander, McDivitt, had been the command pilot for Gemini 4, and his backup was Charles "Pete" Conrad Jr. The Lunar Module pilot, Schweickart, was making his first spaceflight, with his backup being Alan Bean, and Command Module pilot Scott had experience as a pilot of Gemini 8; his backup was Richard "Dick" Gordon. This backup crew served as the prime crew for the Apollo 12 mission.

After the initial ascent it was time to test the docking between the unmanned LM, which was given the nickname Spider, still attached to the third stage of the Saturn V rocket, and the CSM module, which was given the nickname Gumdrop. During the second orbit of Earth the two modules docked before jettisoning the remainder of the Saturn V rocket. This was the first hurdle to overcome before what would turn out to be an extremely fruitful ten days in space.

> "You don't get in a suit and go outside in space if you're going to have motion sickness - that will kill you" Rusty Schweickart

Above: Rusty Schweickart was the first to test the Apollo extravehicular mobility unit

Right: 3 March 1969 saw Apollo 9 launch atop a Saturn V rocket



The CSM, Gumdrop, was imaged from the LM, Spider, over New Mexico

03/03/1969

On the third day of flight, McDivitt and Schweickart suited up in a new-and-improved design based on the Gemini days and prepared to board Spider. During this time on board the LM they conducted systems checks and fired the module's descent rockets to simulate the throttle pattern that would be used during a lunar-landing mission. During this time Schweickart wasn't feeling too great due to the nausea he was experiencing. In fact, commander McDivitt had reported that he had vomited on two occasions.

This nausea comes from the effects of weightlessness on the organs of balance in the inner ear. With these organs not functioning properly under the effects of gravity, astronauts can become susceptible to space sickness. The Lunar Module pilot's nausea pushed back some of the crew's operations, including the first Apollo extravehicular activity (EVA). "We had to postpone the EVA because I had motion sickness the day before, and you don't get in a suit and go outside in space if you're going to have motion sickness, because that will kill you," recalls Schweickart.

This delay caused the crew to be behind schedule, so the EVAs for Schweickart and McDivitt would be restricted to just one daylight pass, and would only include the opening of the hatches of the Command Module (CM) and the LM. This wasn't a disaster, it just meant that the crew were behind a bit and restricted with their valuable time. It was the fourth flight day that saw the two venture outside the confines of the spacecraft and see the vast emptiness of space and all its beauty. The plan was that Schweickart would exit Spider, transfer to the open hatch of the CM and then return - all of which had to be done in the space of just over two hours. Schweickart once again suited up, this time wearing the new extravehicular mobility unit backpack which provided constant communication and oxygen, as well as having water circulate the suit in order to keep his body cool. After the module was depressurised and the hatch was open, the only thing keeping the Lunar Module

The crew

Russell "Rusty" Schweickart

Lunar Module pilot

Apollo 9 was Rusty Schweickart's only flight in space, and he was later the backup commander for the first manned Skylab mission which flew in 1973.

David R. Scott

Command Module pilot

David Scott had been in space once before the Apollo 9 mission. His first spaceflight was as the pilot for Gemini 8 alongside Neil Armstrong. He was later commander of Apollo 15, becoming the seventh person to walk on the Moon.

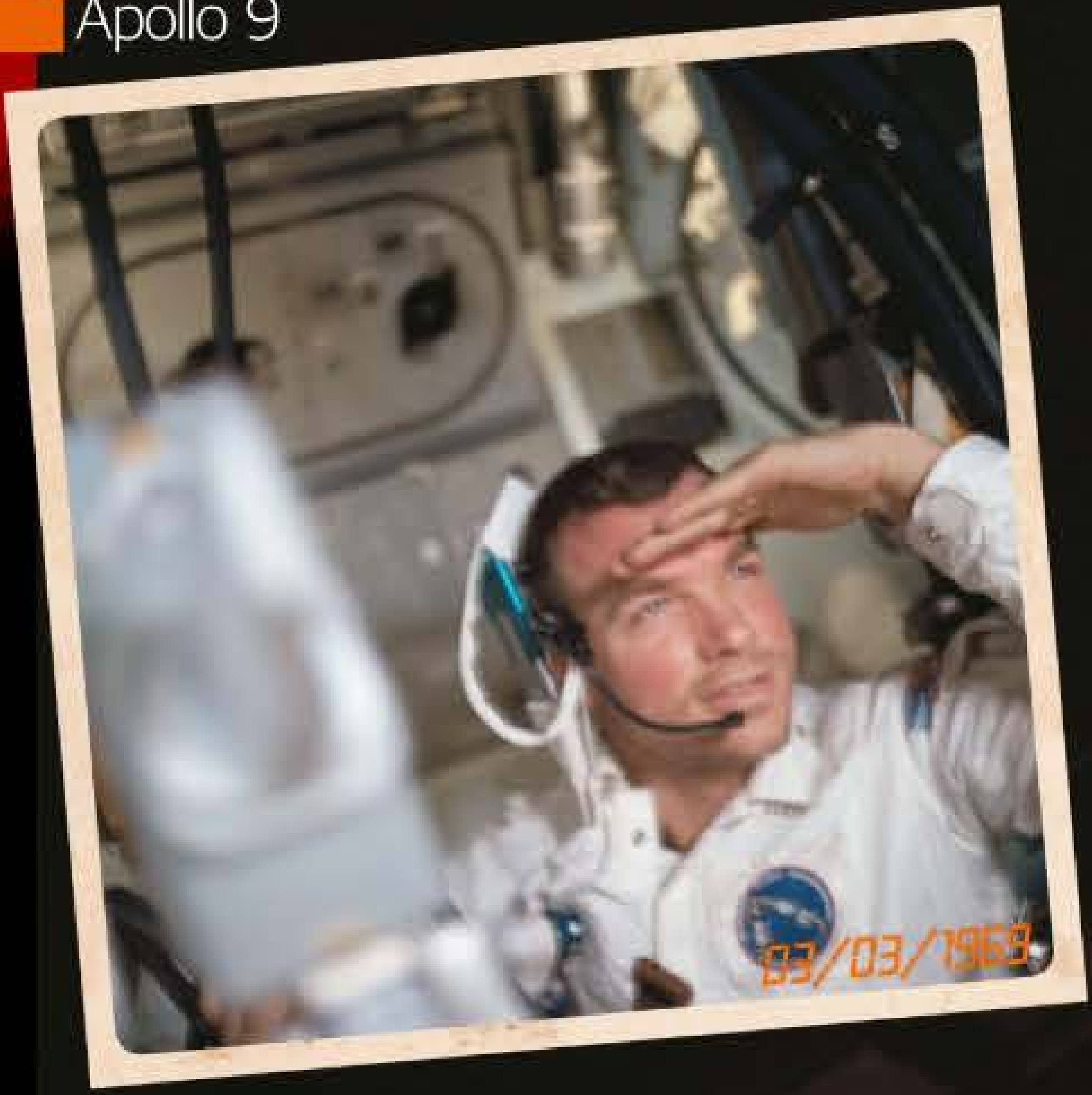
James A. McDivitt

Commander

James McDivitt had been into space once before as commander of the Gemini 4 mission during which Ed White performed the United States' first spacewalk.

25/02/1969

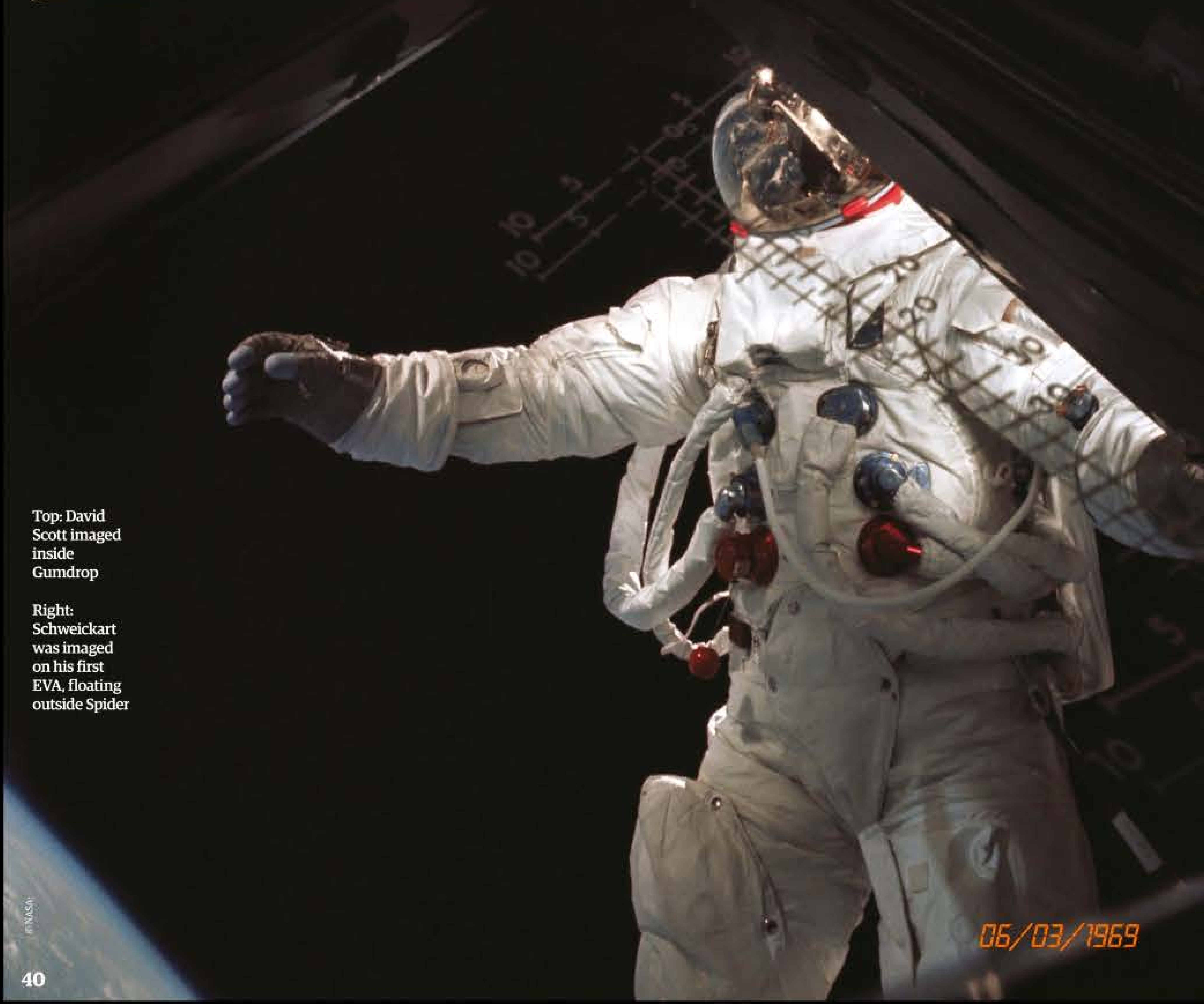
© NASA; Rolls Press/Popperfoto/Getty Images



03/03/1969

The aims of Apollo 9

1. Overall check of the launch vehicle and spacecraft systems
2. First flight of the Lunar Module and performing rendezvous and docking procedures with the Command Service Module
3. Test the extravehicular mobility unit backpack for future spacewalks



06/03/1969

Top: David Scott imaged inside Gumdrop

Right: Schweickart was imaged on his first EVA, floating outside Spider

© NASA

pilot tethered to the spacecraft for just over an hour was a seven-metre (25-foot) nylon rope.

Schweickart recalls his EVA fondly, saying, "I remember being way up the front of the Lunar Module with my hand on the handrail, and I just let go. With one hand I swung myself around and looked at the Earth; the Command Module was also in that direction, but mainly I could see the Earth, the black sky and the black universe above it. I just said to myself: 'This is my time to be a human, not to be an astronaut. I'm not going to think about what's next on the checklist. My job is to be a sponge, to just let this come in through the spacesuit and into me as a human being.' And that happened."

> "I remember being way up the front of the Lunar Module with my hand on the handrail, and I just let go" Rusty Schweickart

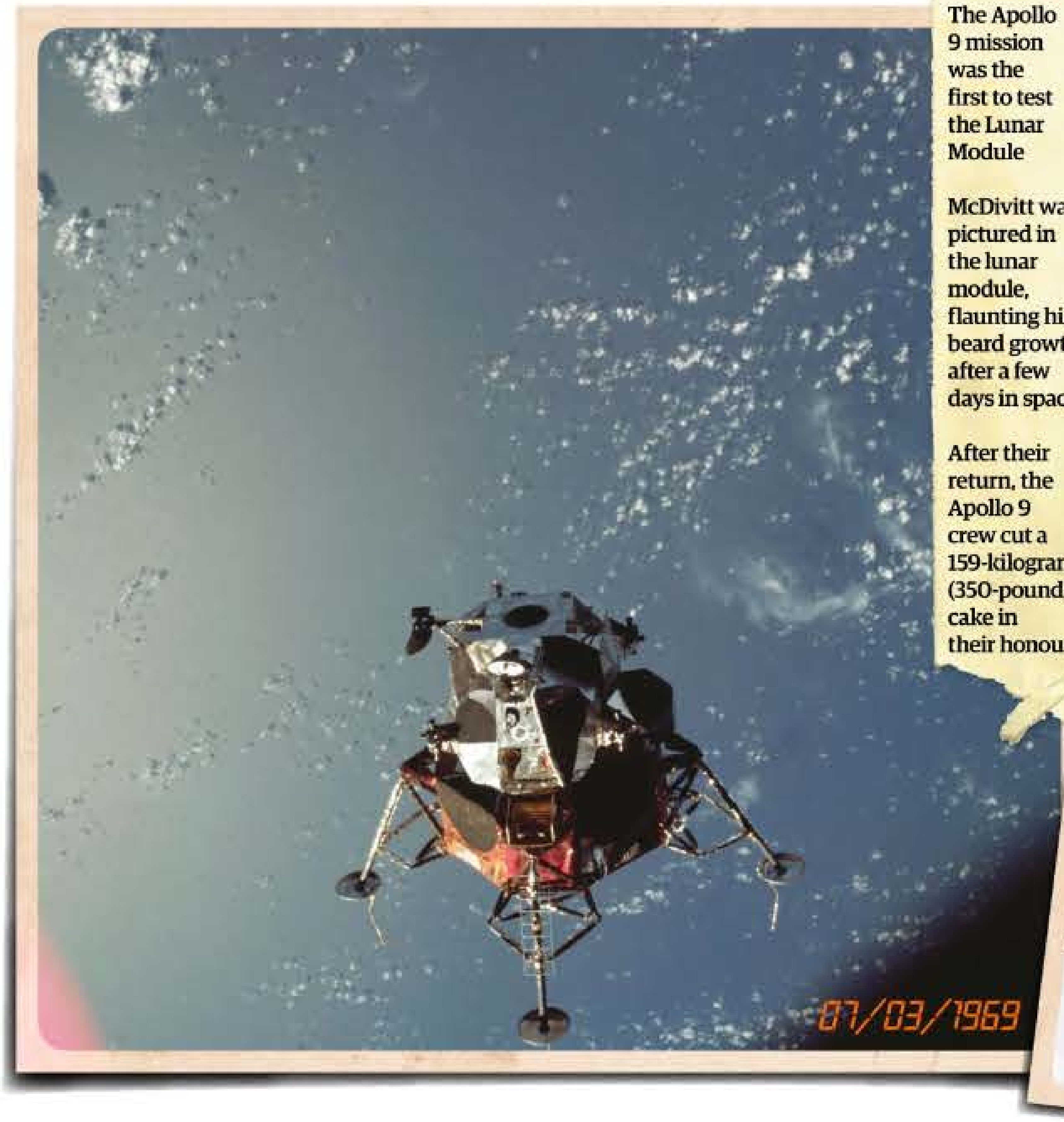
Scott also completed an EVA in this time, but was reliant on the CMS systems for life support. This spacewalk was also over the space of an hour, and in that time both the Command and Lunar Module pilots took photos of space and retrieved thermal samples from outside the spacecraft.

The fifth day held a new test – the crewed undocking and rendezvous of the LM and CSM. In Spider were McDivitt and Schweickart, with Scott remaining in Gumdrop. After months of simulations and training on the ground, the time had come to cut the cord and see if the LM would be capable of lowering humans down to the Moon. When undocking began, something wasn't right. "There were some very small little latches that had to release, and in the simulator on the ground, when we did the procedure everything worked well. When Dave [Scott] pushed the switch and let it go in the actual situation, the probe had not fully extended. He just hit the switch and let it go – which is what we did in the simulator on the ground – but when it reached the end of its travel pushing the Lunar Module away, those little latches, as soon as he let go, went back out, and so we went 'clunk' and stopped," says Schweickart.

"We kind of looked at each other and wondered, 'what was that?'. McDivitt and I said we should probably redock and figure out what happened. We wanted to let the ground team work through it and figure out what happened, and then do it again. At about that time Dave looked up and saw that we weren't separated, and he just hit the switch again. As we started to drift off, we looked at each other and said: 'Well, too late now! So we'll find out when we come back from the rendezvous in eight hours if anything is wrong.'"

After the eight hours the crew had successfully redocked to the CSM, and the experience was deemed a massive success! The final four days of the mission did not include any major tests or experiments that would affect the following Apollo missions. Instead, the Apollo 9 crew conducted Earth resource and multispectral terrain photography experiments over the southern United States, Mexico, Brazil and Africa.

On 13 March 1969, the tenth day of flight that saw them complete 151 revolutions around Earth, the crew made a successful splashdown into the Atlantic Ocean – about 549 kilometres (341 miles) north of Puerto Rico. This concluded what was a massive success for the Apollo program and NASA. "The primary lesson from our experience on Apollo 9 was that everything worked well. We'd had a lot of problems in Gemini doing EVAs with a suit, and they were largely unsuccessful, but we had the brand-new suit. I had to go on the EVA, the first experience of going outside, and fortunately, nothing really dangerous happened. We also had the backpack that was going to allow us to run around on the Moon, so that was a very important test that we did in Apollo 9," concludes Schweickart.



07/03/1969

The Apollo 9 mission was the first to test the Lunar Module

06/03/1969

McDivitt was pictured in the lunar module, flaunting his beard growth after a few days in space

13/03/1969

After their return, the Apollo 9 crew cut a 159-kilogram (350-pound) cake in their honour

WHAT'S NEW AT SATURN?

Cassini is the gift that keeps on giving when it comes to discoveries

Reported by Lee Cavendish

It's been over a year since the demise of NASA's Cassini spacecraft, yet astronomers are still carefully analysing the data it transmitted back to Earth in an attempt to answer the many questions that surround the ringed gas giant. In the space of less than a week scientists made two separate discoveries about fundamental aspects of the planet: how long is a day on Saturn, and how old are its rings?

Determining a day on Saturn is harder than it appears. On Earth it is simply how long it takes for the whole body to complete one rotation, whereas Saturn's gaseous exterior makes it difficult to track any type of consistent rotation. The answer wasn't hidden in the planet, however; it was hidden in its rings. Christopher Mankovich, a graduate student in astronomy and astrophysics at UC Santa Cruz, studied the vibrations of the rings corresponding to the vibrations within the planet itself, and this analysis revealed the length of a day on Saturn to be 10 hours, 33 minutes and 38 seconds.

"The researchers used waves in the rings to peer into Saturn's interior, and out popped this long-sought, fundamental characteristic of the planet. And it's a really solid result," says Cassini project scientist Linda Spilker. "The rings held the answer."

The rings also hold their own mysteries, such as their origin. Towards the end of Cassini's lifetime the spacecraft underwent dives through the rings, which consist of dust, rocks and ice. This passage let Cassini feel the effects of Saturn's gravity on the rings, and the radio signals of the gravity science data were sent back to Earth to reveal the age of the famous cosmic halo. The results from this study indicate that the rings were formed between 10 million and 100 million years ago. To put that into perspective, Saturn's rings were forming around the same time dinosaurs were roaming around planet Earth.

"Only by getting so close to Saturn in Cassini's final orbits were we able to gather the measurements to make the new discoveries," says Cassini radio science team member Luciano Iess of Sapienza University of Rome, Italy. "And with this work Cassini fulfils a fundamental goal of its mission: not only to determine the mass of the rings, but to use the information to refine models and determine the age of the rings."

Although these results may seem to go under the radar, they are fundamental for future research. The only way to answer the more complicated questions about Saturn and its evolution is by understanding its simplest aspects and building from there. For instance, now the age of the rings can be well constrained, astronomers can try and figure out how the rings formed. This rules out any ideas that the rings formed early on in the planet's life after its formation 4.5 billion years ago. Instead it's more likely that a comet wandered too close to Saturn and its gravity dismantled it or there was an event that destroyed one of Saturn's ancient icy moons.

Cassini made its final plunge into Saturn's atmosphere in September 2017

© Tobias Roetsch/Adrian Mann

LEARN TO INSPIRE

www.dphotographer.co.uk

Fujifilm GFX 50R £3,999 medium-format camera fully field tested
Digital Photographer
Practical advice for enthusiasts and pros
WORK WELL WITH WIDE ANGLES
COMPOSITION FOCUSING PANORAMAS PRO ADVICE
GROUP TEST ZOOMS FOR LANDSCAPES
SHOOT & EDIT DRAMATIC LIGHTING EFFECTS MADE EASY
FREE BONUS CONTENT
Expert editing tutorials, Lightroom presets and more
NEWBORN PORTRAITS NIK COLLECTION CONTROL AMBIENT LIGHT
PRO WAYS TO SHOOT MORE SPONTANEOUSLY
ENHANCE THE LIGHT
UNLOCK YOUR KIT'S POTENTIAL
MIRRORLESS or DSLR?
BETTER BIRD PHOTOGRAPHY
NIKON Z 7

EVERY ISSUE • FREE RESOURCE DOWNLOAD

Digital Photographer

Available from all good newsagents and supermarkets

ON SALE NOW

Essential ingredients of landscapes > Macro > Creative Portraits

LANDSCAPE TIPS

SHOOTING ADVICE

WILDLIFE PHOTOS

PORTRAIT GUIDES

CAMERA REVIEWS

BUY YOUR ISSUE TODAY

Print edition available at www.myfavouritemagazines.co.uk
Digital edition available for iOS and Android

Available on the following platforms

Print Tablet Phone Desktop

facebook.com/DigitalPhotographerUK twitter.com/DPhotographer

THE MILKY WAY'S BIG C

RASH

© Nicholas Forder

One of our satellite galaxies is travelling much faster than we thought - and it's aiming to hit our home galaxy

Reported by Ian Evenden

What are you doing in about 2.4 billion years? If you're free, you might be in for a treat when one of the Milky Way's satellite galaxies drops in.

Known since prehistory, the Large Magellanic Cloud (LMC) is one of the most easily spotted of the Milky Way's 59 known satellites. As long as you're in the Southern Hemisphere it's visible with the naked eye along with its diminutive sibling, the Small Magellanic Cloud. Satellite galaxies orbit larger ones, caught up in their gravity and occasionally merging with them. The LMC is a fast-moving galaxy, 14,000 light years across, and has probably been in our galactic neighbourhood for around 1.5 billion years. It was previously expected to continue orbiting, or even escape the Milky Way's pull. Our home galaxy is much larger, 100,000 light years in diameter, so exerts a gravitational effect on its satellites.

New research, however, has discovered that the LMC contains almost twice as much dark matter as was previously thought, giving it more mass and changing how it moves. This additional density changes the cloud's destiny – it's going to collide with the Milky Way.

Using the Evolution and Assembly of GaLaxies and their Environments (EAGLE) computer simulation at the University of Durham, a team of scientists simulated the interactions between the two galaxies, and it turns out the LMC has just finished a close pass by us. "Right now the LMC is going away from our galaxy," says Dr Marius Cautun, part of the team that made the discovery. "But in many millions of years it will start approaching again. In about 1.5 billion years it will have another close encounter with our galaxy, however, this time it will come much closer, to within about 45,000 light years. This will strip stars from the disc of the LMC. Those stars will form long and extended tidal arms, similar to the present-day Sagittarius Stream [stars stripped from the Sagittarius Dwarf Spheroidal Galaxy] but much brighter. Our descendants could see bright streams of stars in the night sky if it takes place on the side of the galaxy where the Sun is."

Soon after this the LMC will head into the Milky Way, but will be a shadow of its former self thanks to its stars having been stripped away. The process is already beginning, even though the gap between galaxies is still quite large – the LMC is losing some of its gas envelope to the Milky Way in a process known as the Magellanic Stream. But what happens when you're hit by the core of a small galaxy?

"The collision will feed the supermassive black hole at the centre of our galaxy," says Cautun. "This would likely lead to it spewing radiation and becoming a quasar." These extremely luminous objects are the cores of giant galaxies and can have masses billions of times more than our Sun. They produce a great deal of energy, even outshining entire galaxies, releasing radiation across the entire electromagnetic spectrum. They're not something you'd want to get close to. Cautun can reassure us on that point, though: "Fortunately, the Sun is far enough from the galactic centre, so any life on Earth

Above: UGC 6945 is a trio of interacting galaxies 570 million light years away. The large galaxy on the left is actually two which have almost finished merging

Right: An extremely bright star-forming region in the LMC, the Tarantula Nebula is the most active such region in the entire local group of galaxies

> "The collision will feed the supermassive black hole at the centre of our galaxy, likely leading to it becoming a quasar" **Dr Marius Cautun**

will not be affected by the radiation from the black hole. However, our descendants would witness a spectacular cosmic fireworks show."

It seems likely the galactic merger won't directly affect our Solar System at all. Earth will have its own problems - the loss of its oceans and the end of plate tectonics leaving it only able to support very simple life underground, with a surface temperature in excess of 100 degrees Celsius (212 degrees Fahrenheit). The LMC could make our Solar System a much more difficult place to live in, however, spelling trouble for any human descendants living on Mars or the moons around the gas giants.

"First it will dislodge other stars from their neat orbits around our galaxy," says Cautun. "This will increase the chances of a close encounter between our Solar System and another star or gas cloud. Such an encounter can do two things: the most likely would change the orbits of Oort Cloud objects, which could come raining down towards the inner Solar System, hugely increasing the chance of an asteroid or comet colliding with a planet. In extreme cases, if a star gets very close to the Sun it could even change the orbits of the planets."

Dr Andreea Font

Dr Marius Cautun

What we know about the Large Magellanic Cloud

It's only visible from the Southern Hemisphere, but just what is this oddly shaped satellite galaxy?

Fourth-largest locally

The LMC is the fourth-largest galaxy in our local group after the Andromeda Galaxy, the Milky Way and the Triangulum Galaxy.

It's named after Magellan...

Explorer Ferdinand Magellan saw the galaxy on a voyage in 1519, but Persian astronomer 'Abd al-Rahman al-Sufi Shirazi wrote about it in 964.

...but it's been known for much longer

The Khoisan people of southern Africa tell a story in which a hero stands on the cloud to shoot at zebra - represented by Orion's belt. The tale could be over 250,000 years old.

It used to be a barred spiral

The LMC's shape is being distorted by the gravity of the Milky Way and Small Magellanic Cloud; its central bar is now off-centre.

It's actively forming stars

The Tarantula Nebula, the most active star-forming region in the local group, is in the LMC. It was home to supernova 1987A, the closest observed since the invention of the telescope.

© NASA, ESA, and the Hubble Heritage Team; Ignacio Diaz Bobillo

Above: The Antennae Galaxies are merging and undergoing rapid star formation, likely the future of our Milky Way when it eventually merges with Andromeda

One slim possibility points to a lonely, cold future for our Solar System: "The chance for this is rather small, about one to three per cent," explains Cautun, "but the collision could put the Solar System on a trajectory that will take it outside our galaxy. Our descendants would see a very different night sky, much darker than it is currently, with only a modest bright patch that will correspond to the Milky Way galaxy. Furthermore, it will be tremendously more difficult for our descendants to travel to other stars if they haven't yet done so by that time. Currently the nearest star is four light years away. However, if our Solar System was pushed outside the Milky Way, the nearest star could be hundreds or even thousands of light years away."

Computer simulations of galaxies are carried out on supercomputers with many thousands of processor cores, and making sure the initial parameters of the simulation are correct is vital to getting a realistic result, as Dr Andreea Font of the Astrophysics Research Institute at Liverpool John Moores University explains: "I've used the EAGLE simulation in the past for another project, and the cosmological parameters are pretty well known, but what's less certain are the astrophysical processes that go on inside galaxies. These are harder to model because there are many processes that can affect the formation of stellar structures."

The simulation is based on physical models for things such as star formation and black holes, all of which are tweaked to produce a realistic result based on observational data: "We know that the majority of galaxies in the local universe are disc galaxies," says Font. "So a simulation, if it's realistic enough, should produce a comparable number of disc galaxies."

The simulations, despite operating on the kind of computer hardware that leaves even the beefiest of home PCs looking very small indeed, are limited

> "If our Solar System was pushed outside the Milky Way, the nearest star could be hundreds of light years away" **Dr Marius Cautun**

The Milky Way's smash up

The LMC follows a complex path as it orbits our home galaxy, but there's only one way it can end

1. Close pass

When it'll happen: The recent past

The LMC passed by the Milky Way at a distance of 130,000 light years, close enough to lose some of its gas envelope to the gravity of our much larger home.

5. Galaxies merge

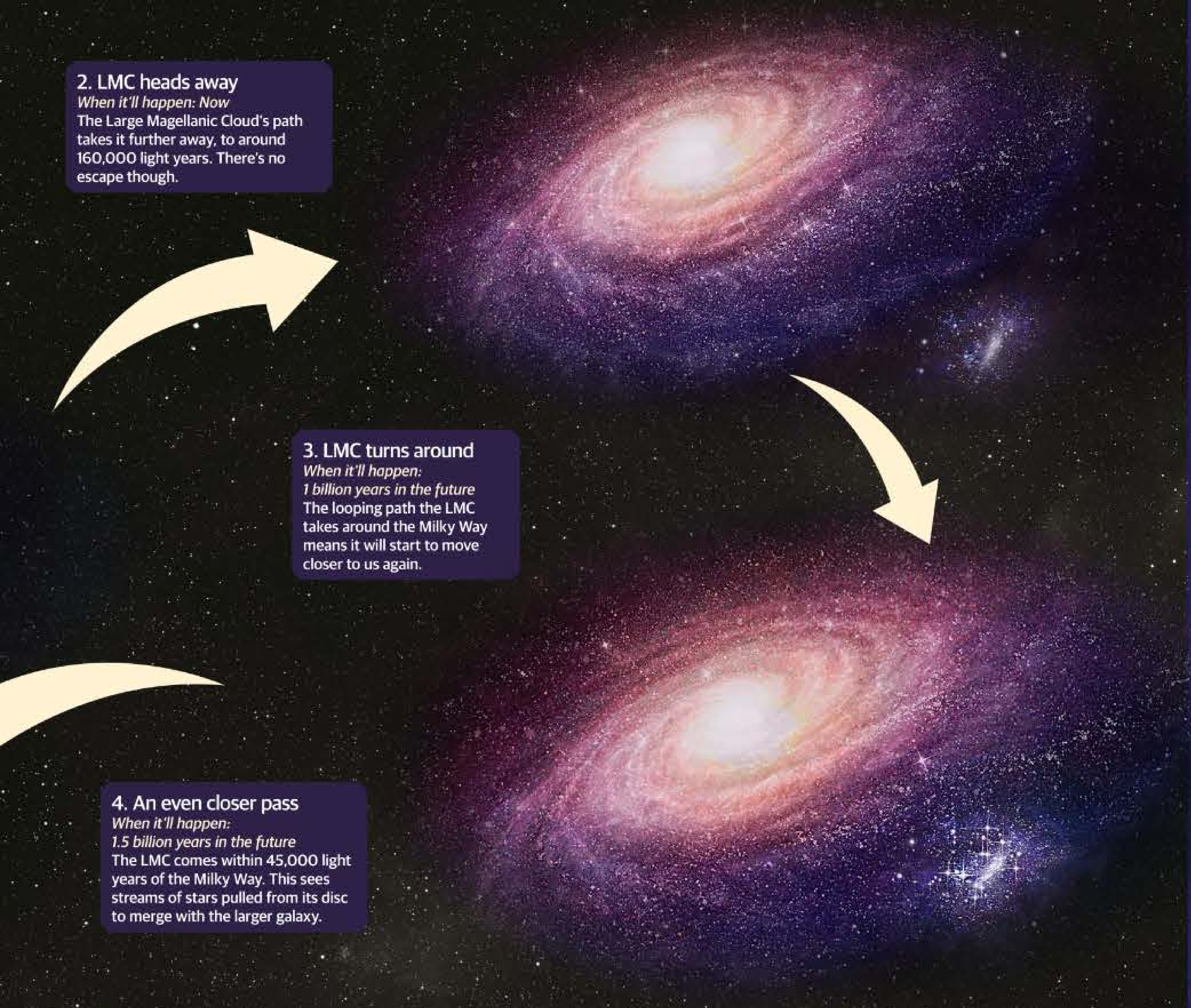
When it'll happen: 2.4 billion years in the future

The core of the LMC merges with that of the Milky Way, kickstarting the supermassive black hole at its core into a quasar and beginning an era of star formation.

6. Andromeda is next

When it'll happen: 5 billion years in the future

The Andromeda Galaxy and the Milky Way merge, producing a giant elliptical galaxy. The entire local group will have merged in 150 billion years time.



2. LMC heads away
When it'll happen: Now
The Large Magellanic Cloud's path takes it further away, to around 160,000 light years. There's no escape though.

3. LMC turns around
When it'll happen:
1 billion years in the future
The looping path the LMC takes around the Milky Way means it will start to move closer to us again.

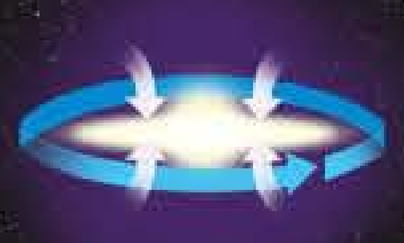
4. An even closer pass
When it'll happen:
1.5 billion years in the future
The LMC comes within 45,000 light years of the Milky Way. This sees streams of stars pulled from its disc to merge with the larger galaxy.

How stars are made

They form when the internal pressure of a gas cloud is no longer enough to overcome its gravitational collapse

Trigger events
An event such as a supernova or galactic merger can trigger the collapse of a proto-stellar cloud.

Heating up
The gas and dust at the centre of a dense area of collapsing gas begins to heat up as it contracts.



Breaking up
Spinning clouds of collapsing gas may break up into two or three blobs. This is why a majority of stars are binary.

Fusion begins
If the protostar reaches 15 million °C (27 million °F), it begins to fuse hydrogen into helium.

Shine like a star
The energy produced by the fusion balances out the contraction. The star is now on the main sequence.

© NASA, ESA, and the Hubble Heritage Team; Nicholas Forder

> "There are some speculations that most of the Milky Way satellites formed following a collision with the Andromeda Galaxy about 10 billion years ago" **Dr Marius Cautun**

in resolution. They're not simulating planets, and possibly not even individual stars, especially when simulating enormous volumes of space. "EAGLE has various degrees of resolution," says Font. "One particle could be a few hundred thousand solar masses. Or more. There's a trade-off of whether you want many galaxies and a coarser resolution, or you want to simulate a single galaxy and have a lot of resolution. You can resolve stellar populations of a few thousand stars, probably not individual stars."

In terms of an entire galaxy made up of hundreds of billions of stars, a resolution of a few thousand stars is enough to give a realistic result. Enough, certainly, to see galaxies attracted to each other's gravity and merge in different ways, as Font explains: "There is one Milky Way, and we're living in it. In a simulation we can test scenarios, so we choose some realistic initial conditions that we hope will result in the formation of disc galaxies [within the simulation] that we hope will be like the Milky Way. EAGLE simulations simulate a large volume, 100 megaparsecs [326.16 million light years] or so on each side, so you'll have hundreds of Milky Way-type galaxies. You won't get the exact LMC/Milky Way merger, but you get potential candidates, and you can wind the simulation back and see how they came about."

Galaxy mergers aren't that rare in the universe; Hubble imaged the merging of two spiral galaxies - known as Arp 256 - in the constellation of Cetus, The Whale, in 2008, but a strange quirk of fate means the Milky Way is long overdue for one. "Most galaxy collisions actually took place in the past when the universe was just a few billion years old," says Cautun. "And now we are in a period when such collisions are becoming rarer.

"For example, we think that our nearest massive neighbour, the Andromeda Galaxy, is experiencing one such collision with the galaxy M32 right now. This collision is much more advanced than our own, with M32 having lost most of its stars. The Whirlpool Galaxy, with its M51b companion, is another example where the collision has barely started. What is especially surprising in the case of our galaxy is that we think it had a very long period, the last 10 billion years, in which it didn't have any such collisions. This is quite unusual for a galaxy as massive as our own. You could say the collision with the LMC is long overdue!"

These might not be the only mergers that have been going on in our galactic neighbourhood. "There are some speculations that most of the Milky Way satellites formed following a collision with the Andromeda Galaxy about 10 billion years ago," says Cautun, "but this view is hotly contested in the astronomy community. Most observations point towards the LMC having entered into the dark matter halo surrounding the Milky Way only recently, one to two billion years ago.

"Maybe more interesting is that the LMC has its own very bright satellite - the Small Magellanic Cloud [SMC]. The are multiple reasons to think that the SMC is in the process of being disrupted and destroyed by the LMC. That likely would have been the end for the SMC, but now that the LMC has come close to our galaxy the gravity of the Milky Way will likely steal the SMC from the LMC, if that hasn't already happened. Unfortunately, our observations aren't currently good enough to have a clearer answer to this question."

It paints a picture of a universe in which large galaxies are hunters, devouring smaller prey and stripping them of their stars and gas. One other side effect of the merger is that it could trigger star formation in the Milky Way, meaning that the night sky of the distant future is guaranteed to look very different to the way it does now, whether or not there are any humans there to gaze up at it.

Inset (right): This globular cluster is thought to have come from the Sagittarius Dwarf Spheroidal Galaxy, which will fully merge with the Milky Way in 100 million years

Right: Supernova 1987A was a Type-II Supernova in the LMC, the closest to Earth observed since 1604

© NASA, ESA, Hubble

FOR PEOPLE WHO ♥ RETRO GAMES

www.retrogamer.net

retro GAMER
RESI-RECTING
RESIDENT EVIL 2
CAPCOM'S YOSHIAKI HIRABAYASHI TAKES US INSIDE THE SEMINAL SURVIVAL HORROR SEQUEL
THE WORLD OF MARIO SPIN-OFFS
CREATING RUFF 'N' TUMBLE
ULTIMATE GUIDE: VIGILANTE
THE MAKING OF DIVINE DIVINITY
MASTERING GALAXY FORCE

retro GAMER

Available from all good newsagents & supermarkets

ON SALE NOW

Resident Evil 2 · Mario Spinoffs · Vigilante · Galaxy Force

CLASSIC GAMES

COOL HARDWARE

BIG INTERVIEWS

COMPANY PROFILES

INSANE ACCESS

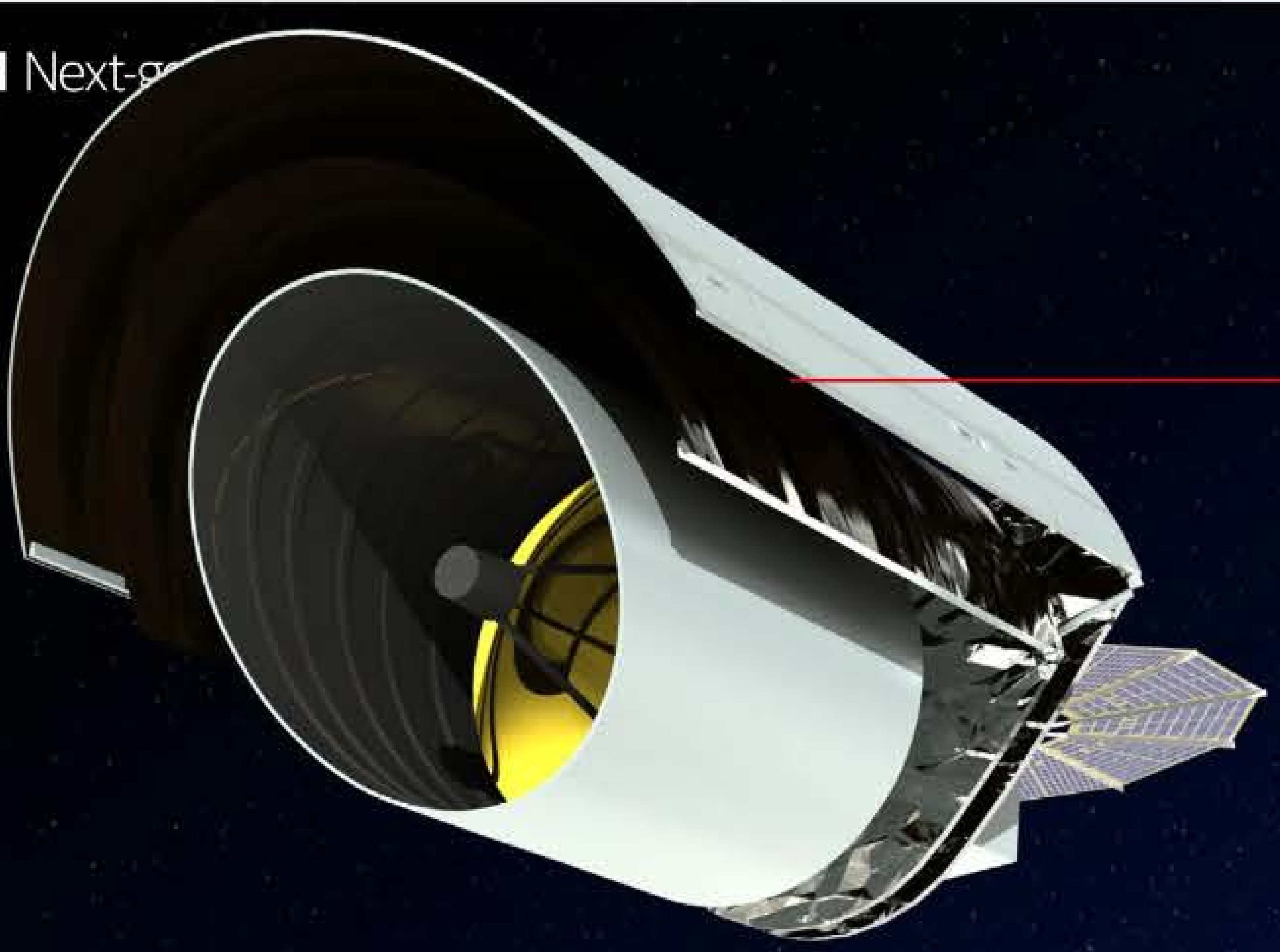
BUY YOUR ISSUE TODAY

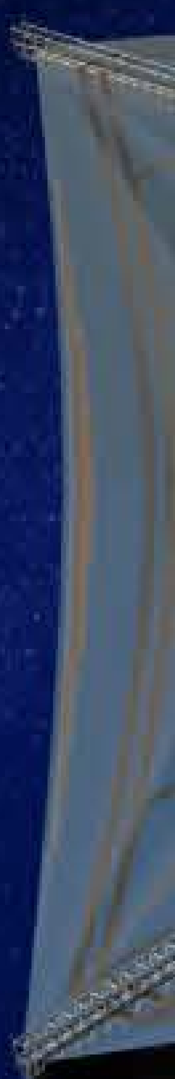
Available at www.myfavouritemagazines.co.uk

Available on the following platforms

Phone Tablet Desktop Print

facebook.com/RetroGamerUK twitter.com/RetroGamer_Mag





THE NEXT GENERATION OF SPACE TELESCOPES

Take a look at NASA's great observatories of the future

Although NASA have yet to launch the James Webb Space Telescope (JWST), now scheduled to launch in March 2021, they have already started planning for a better telescope to become its successor. At the 233rd meeting of the American Astronomical Society (AAS) in Seattle, Washington, US, four mission-concept studies were presented to show the future of space telescopes. But of these four, only one will launch in the mid-2030s.

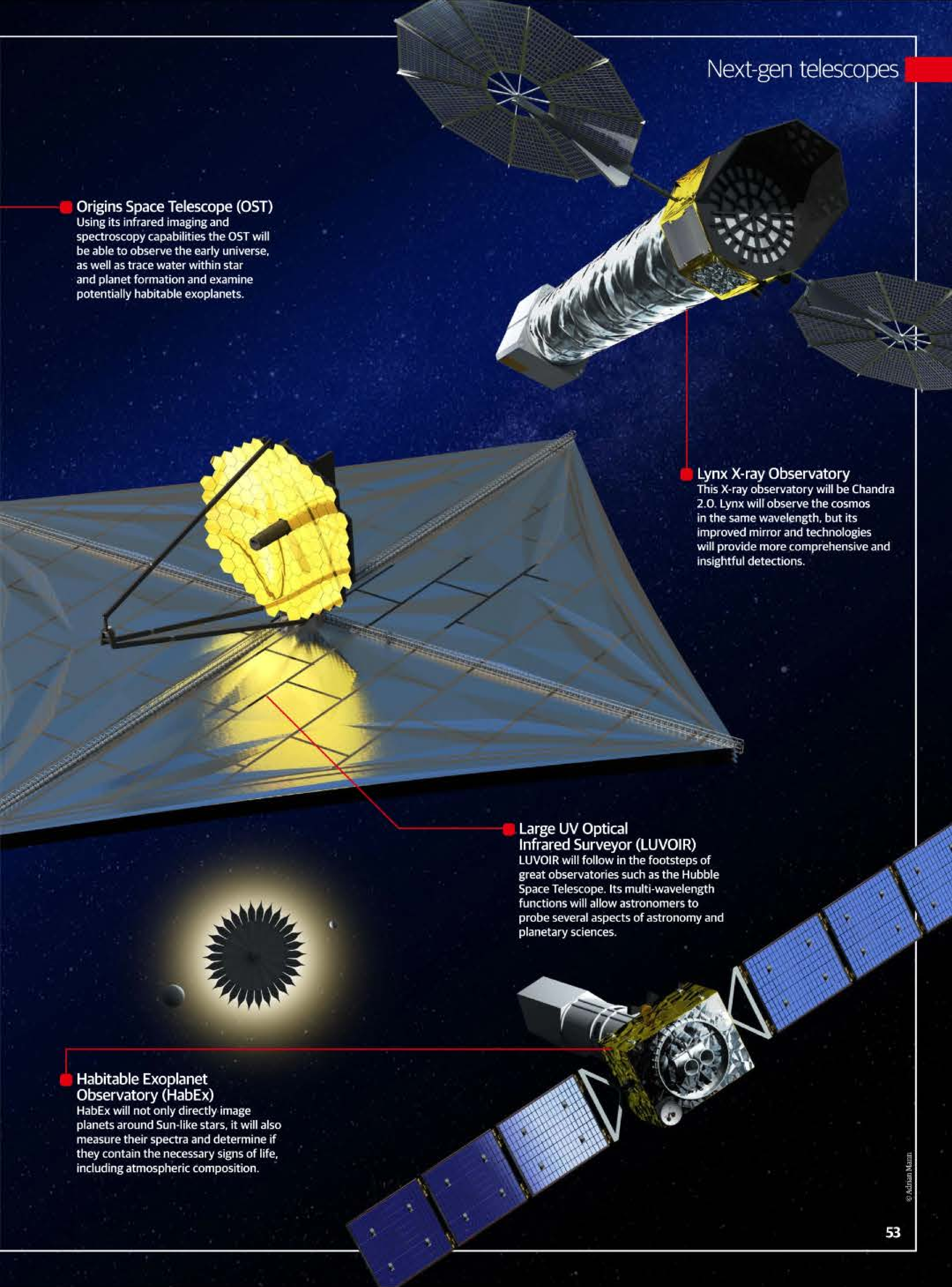
These proposed missions will explore the universe in a range of wavelengths that will reveal incredible details about exoplanets, galaxies, black holes, stars and even objects in our own Solar System. NASA has yet to put any price tags on these missions due to their preliminary status, but these type of flagship-class missions typically cost over $1 billion (£771 million) – the JWST is estimated to cost over $10 billion (£7.7 billion).

One of the missions will look at the far-infrared universe and peer into the dust clouds that are scattered across space in order to investigate how stars and planets are formed. This telescope, the Origins Space Telescope (OST), will be 15 metres (50 feet) in diameter, which is four-times the size of the European Space Agency's Herschel Space Observatory.

Another mission will look at potentially habitable exoplanets around Sun-like stars at wavelengths from near-infrared to ultraviolet. The Habitable Exoplanet Observatory, or HabEx, will deploy a large, sunflower-shaped starshade that will block the light of the star in order to directly observe the orbiting exoplanet, much like how a coronagraph blocks out the Sun's light to observe the corona. The telescope itself will have a mirror diameter of four metres (13 feet), with the starshade stretching out to a much larger 72 metres (236 feet).

Another candidate is the Large UV Optical Infrared Surveyor (LUVOIR). As its name suggests it will look to observe the universe in multiple wavelengths. Think of it as a new-and-improved Hubble Space Telescope. This telescope, with a mirror diameter six-times that of Hubble's, will be able to stare into the early stages of the universe. By being able to study the first galaxies and the reionisation period that took place not long after the Big Bang, our evolution throughout time and space will become more apparent.

Last but not least is the Lynx X-ray Observatory, the potential successor to NASA's Chandra X-ray Observatory. It has the potential to be two orders of magnitude higher in sensitivity than Chandra as it looks at the most energetic events to occur throughout the cosmos, such as black holes from the earliest galaxies and newly born stars. To put that into perspective, Chandra can study stars as far away as 1,300 light years, but with Lynx that figure will increase up to 16,000 light years – over 12-times farther!



Origins Space Telescope (OST)
Using its infrared imaging and spectroscopy capabilities the OST will be able to observe the early universe, as well as trace water within star and planet formation and examine potentially habitable exoplanets.

Lynx X-ray Observatory
This X-ray observatory will be Chandra 2.0. Lynx will observe the cosmos in the same wavelength, but its improved mirror and technologies will provide more comprehensive and insightful detections.

Large UV Optical Infrared Surveyor (LUVOIR)
LUVOIR will follow in the footsteps of great observatories such as the Hubble Space Telescope. Its multi-wavelength functions will allow astronomers to probe several aspects of astronomy and planetary sciences.

Habitable Exoplanet Observatory (HabEx)
HabEx will not only directly image planets around Sun-like stars, it will also measure their spectra and determine if they contain the necessary signs of life, including atmospheric composition.

© Adrian Mann

ASK Space

Our experts answer your questions

Astronauts must undergo a vigorous training regime before they can reach space

SPACE EXPLORATION

What are the fundamental characteristics needed for someone to become a successful astronaut?

Some of the simple things are an outrageously healthy body, because you have to be able to pass the hardest physical in the world to be deemed safe to send to the space station, and the second is a proven ability to learn complicated things. We tend to choose folks who have an advanced university degree, because if you have a PhD in polymer chemistry then you've shown you can learn complicated things.

The third is a proven ability to make good decisions when the irreversible consequences are high. So how do you choose someone who has shown that they're not only a healthy student, but also someone who can react appropriately and make good calls in a highly stressful, high-threat environment.

Then, to a large part, there's psychology: what type of person are they? Is this someone I'd want to fly in space with? Would I trust this person with my life? And would I want to be on board a spaceship for six months with them? So that's the list of things we're looking for.

Chris Hadfield is a retired Canadian astronaut who flew on two Space Shuttle missions and was also commander of the ISS

EXOPLANETS

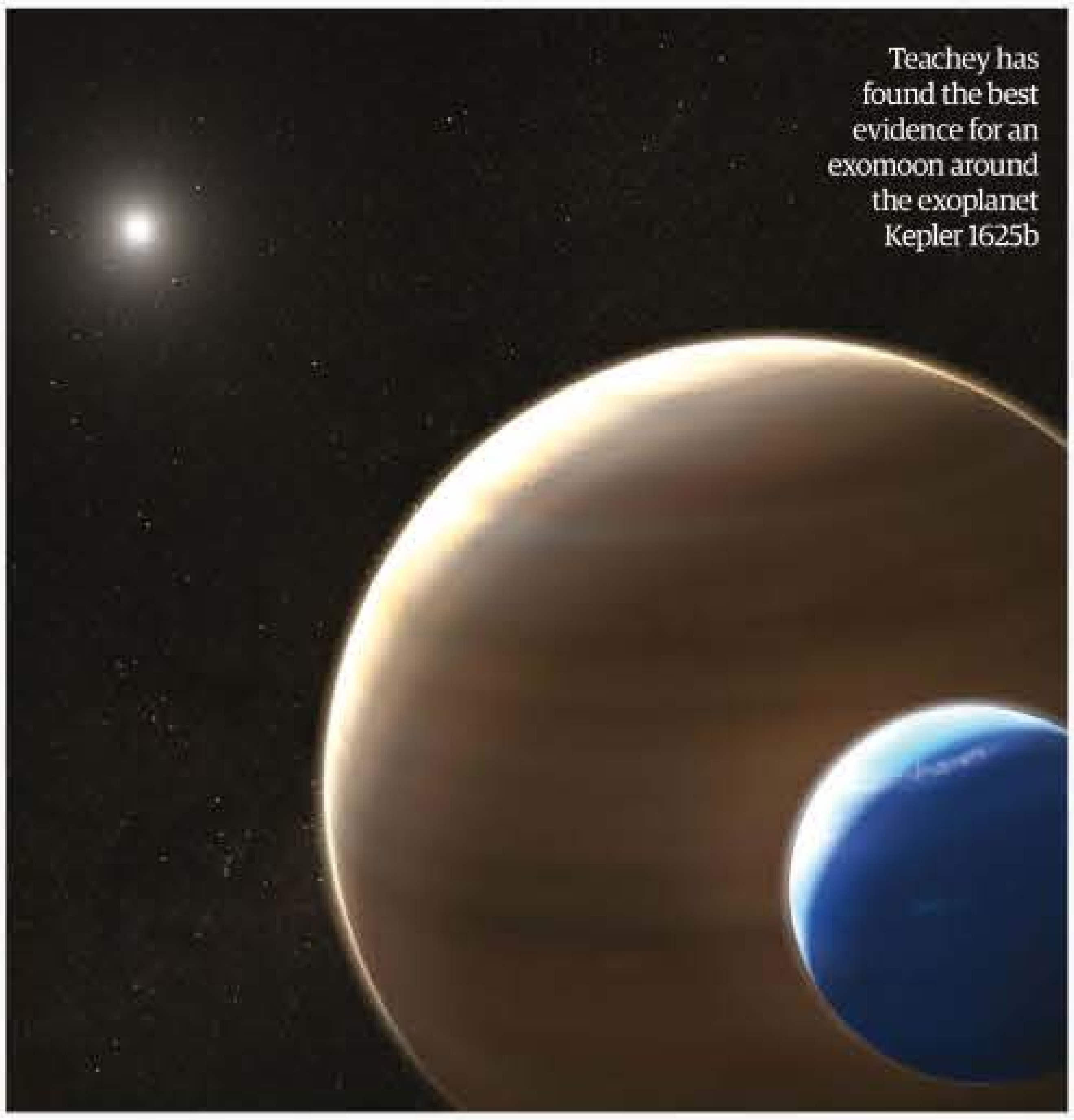
What does the discovery of exomoons tell us about the universe?

First of all, I think that they could really tell us a lot about the formation of our Solar System, and the formation of other stellar systems. Certainly they tell us about the system we see them in, but the question always arises about life evolving on Earth. Were these circumstances on Earth very common across the galaxy, or were they very special? I think that it's very much an open question.

Exomoons can play a part in answering that question, because we've seen moons all over the place in our Solar System, and there's good reason to think they could be elsewhere. Until we see moons it's very much an open question whether we've got an unusual formation history, or whether this is something that happens all over the place.

So that's one thing. I would say that we are still very much interested in the idea of habitable moons. There are interesting places in our own Solar System such as Europa, Enceladus, Titan and other places that are very intriguing, and could even be habitable. If similar moons turn out to be habitable in other parts of the galaxy, then this expands the number of places where life could arise.

Alex Teachey is an astronomy PhD candidate at Colombia University, New York, United States



Teachey has found the best evidence for an exomoon around the exoplanet Kepler 1625b

SPACE EXPLORATION

Can the cost of space exploration be justified?

Yes, absolutely it can. I know that some might argue that if we are spending public taxes on scientific research, then why don't we focus it on more immediate challenges such as tackling climate change, or antimicrobial resistance, or finding cures for cancer and so on. People seem to think that space missions are a luxury, but I would come at it from a different direction.

Firstly, many space exploration missions in the future will be privately funded or a collaborative effort between many countries. Secondly, I would suggest we compare how much it costs to fund a space mission with how much many countries spend on defence. In any case, this is more than just curiosity-driven blue-sky research. Space missions help us develop new technologies that then get used in so many unexpected ways.

For me as a scientist, space exploration is about answering some of the deepest questions, such as whether there is life elsewhere in the universe. If we stop seeking answers to questions such as this then that takes away from our very humanity.

Jim Al-Khalili is a popular science communicator and professor of physics at the University of Surrey, United Kingdom

Space exploration missions have been performed for several decades

© NASA; ESA

ASK Space

Our experts answer your questions

ASTROPHYSICS

What is the difference between a quasar and a blazar?

Both quasars and blazars are members of the family of active galactic nuclei (AGN), galaxies with energetic output dominated by activities in their centres as a result of strong accretion into supermassive black holes.

Quasars are luminous AGN featuring blue-colour continua and broad emission lines in their spectra. Both components are generated by thermal processes from gas/dust close to the central black hole. Blazars are AGN with emissions dominated by non-thermal components such as strong radio and X-ray emissions combining from jet, and strong variabilities over a short time.

This difference is understood as a result of viewing angles. Blazars are viewed almost directly along the jet, and the relativistic effect magnifies the jet emission to the extent that it dominates the thermal component. In other words, blazars are quasars viewed 'down the barrel'. This picture is largely supported by observations, although details of jet production in AGN and its cosmic evolution is still an open question.

Xiaohui Fan is the Regents' Professor of Astronomy at the Steward Observatory

A blazar is essentially a quasar viewed from a different angle of orientation

© NASA/JPL-Caltech; University of Warwick/Mark Garlick

EXOPLANETS

Why is it easier to detect exoplanets around M-dwarf stars as opposed to Sun-like stars?

It isn't. About 3,900 exoplanets have been confirmed in 2,900 exoplanetary systems across all host-star spectral types, primarily with indirect detections via the transit and radial velocity methods. While M-dwarfs constitute about 75 per cent of the stars in our galaxy, only about three per cent of now-known exoplanets are hosted by M-dwarf stars.

M-dwarfs are physically smaller than other dwarf (main sequence) stars of other spectral types. So, if all other things were equal, the 'dip' of a transit signal due to the area covered by equally sized planets obscuring a fraction of the light from differently sized stars would be greater, and easier to detect, in M-dwarf systems. However, M-dwarfs are intrinsically much fainter than other dwarf stars, ranging from only seven per cent as luminous as the Sun for the very brightest to a minuscule 0.02 per cent for the faintest. This relative faintness also

ASTROPHYSICS

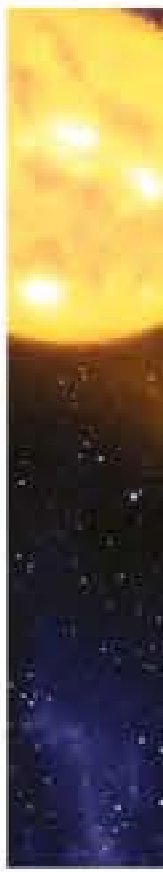
How is a black hole created?

Normal stars come in a range of sizes. The smallest are only slightly larger than large planets like Jupiter. The largest are perhaps a hundred-times as massive as our Sun. There is still some discussion on how massive a star can be, since very massive stars are thought to become unstable.

Stability is what really defines a normal star. To ensure stability, some force has to oppose their internal gravity. We know this is due to thermonuclear reactions inside them. The observations of solar neutrinos settled that. Energy release from those reactions requires the proper elements and conditions, like high pressure and temperature. Once the reactions stop, the force holding up the star inside stops and the star starts collapsing upon itself from the inside first.

If the star is very massive then the centre can collapse in a very small volume and create a black hole. Eventually the outer layers will then either fall in as well, or be blown off by the release of energy from the in-falling parts.

Paul Kuin is an astrophysicist at University College London (UCL), United Kingdom

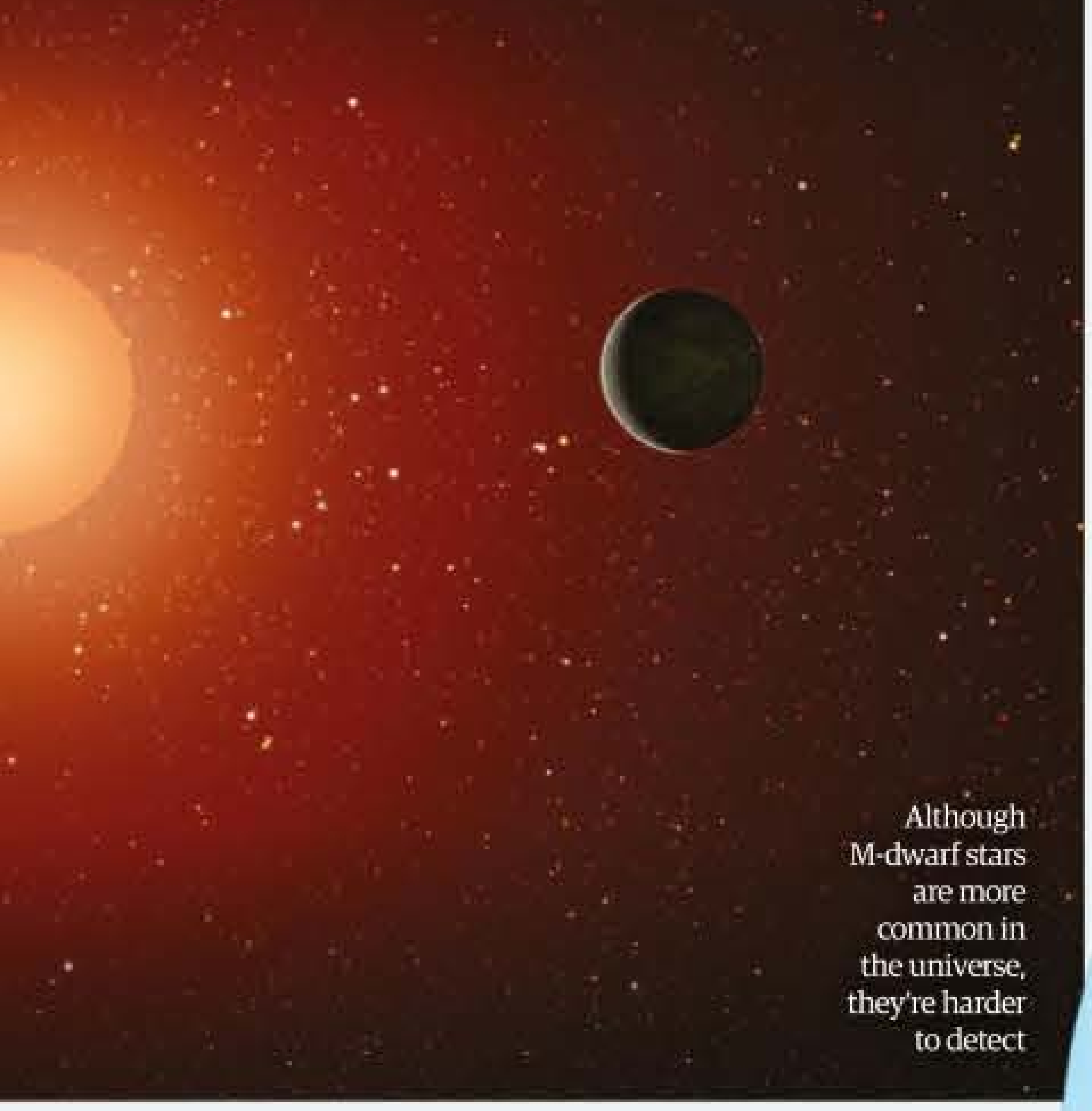


Did you know?

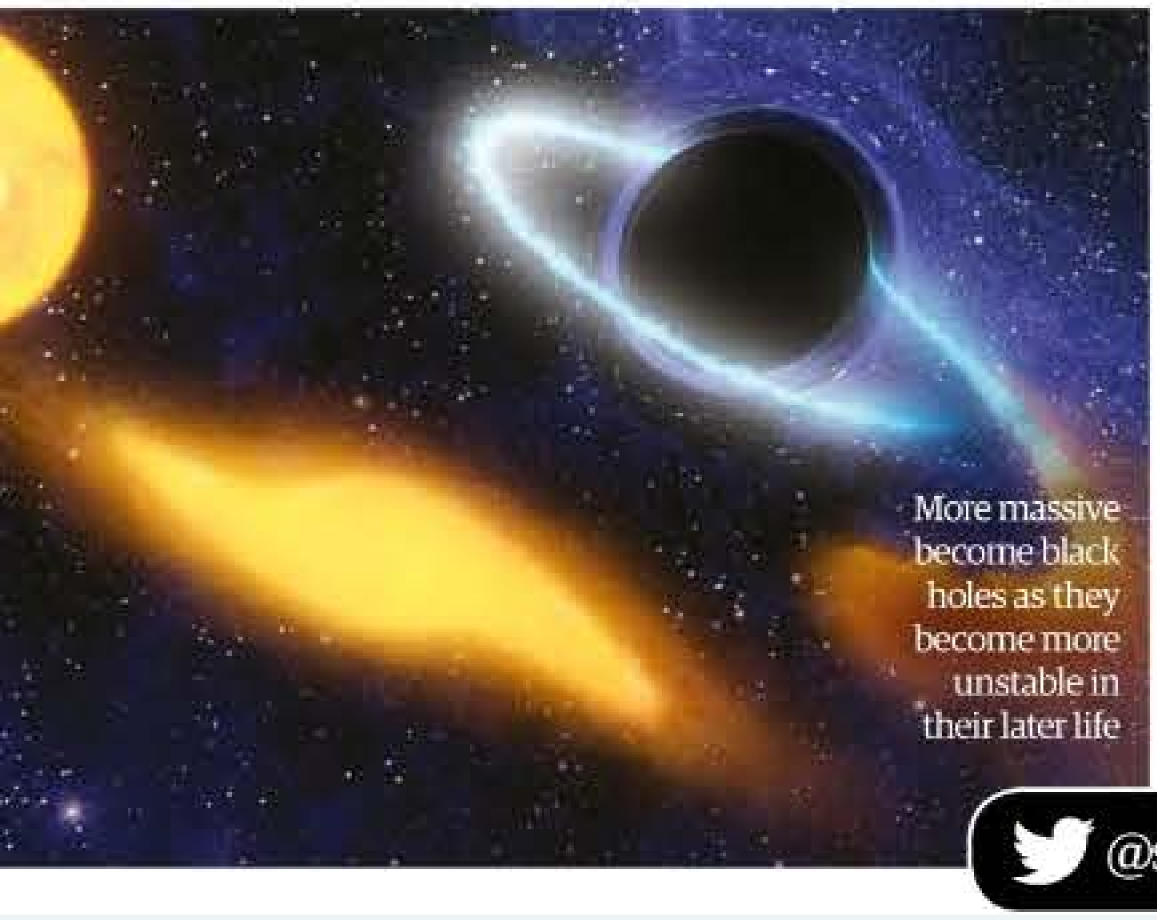
Our Sun is a main sequence star, as are its closest neighbours Sirius and Alpha Centaurai A. These stars are powered by converting hydrogen into helium.

adversely affects the sensitivity of detections by the radial velocity method. Thus, M-dwarf stars present a much greater observational challenge, in particular at distances farther from the Earth.

Glenn Schneider is an astronomer at the University of Arizona's Department of Astronomy and Steward Observatory



Although M-dwarf stars are more common in the universe, they're harder to detect



More massive become black holes as they become more unstable in their later life

ASTROPHYSICS

How can stars create crystals?

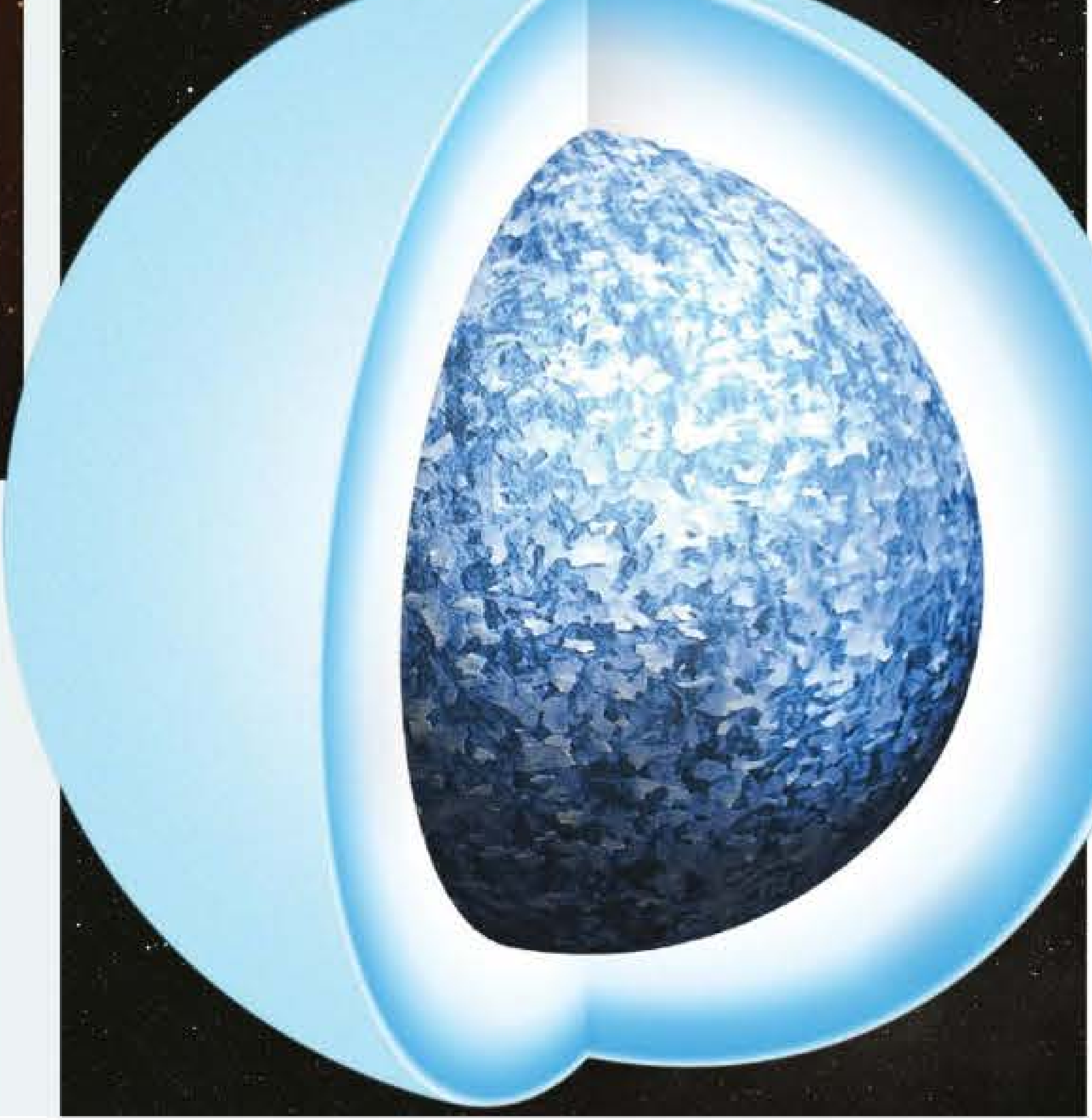
Regular stars like the Sun remain gaseous because they have a nuclear source of energy. But when the Sun dies it will become a large red giant star for a short time, and then a compact white dwarf made of carbon and oxygen, corresponding to the inert nuclear waste of helium burning.

Without any source of energy white dwarfs are bound to cool over timescales of billions of years. After a few billion years of cooling the liquid interior abruptly transitions into a solid, which slows down the evolution. It is much like if you were doing the experiment on freezer water. If you used a thermometer you would realise that it remains at the same temperature for a while before it cools down more rapidly. This is because latent heat, or transformation energy, is released during solidification.

The same happens in white dwarfs where the freezer is the dark and empty universe, but the transition happens at ten million degrees because of the densities involved. The atoms are ordered in a cubic lattice because it minimises the potential energy. The thin surface layers of the white dwarf (less than one per cent of the mass) will remain gaseous for another 10 to 20 billion years until they reach room temperature. After that, the white dwarf is a fully solid crystal and stable for at least 10 to the power of 20-times the current age of the universe!

Pier-Emmanuel Tremblay is an assistant professor at the University of Warwick, United Kingdom

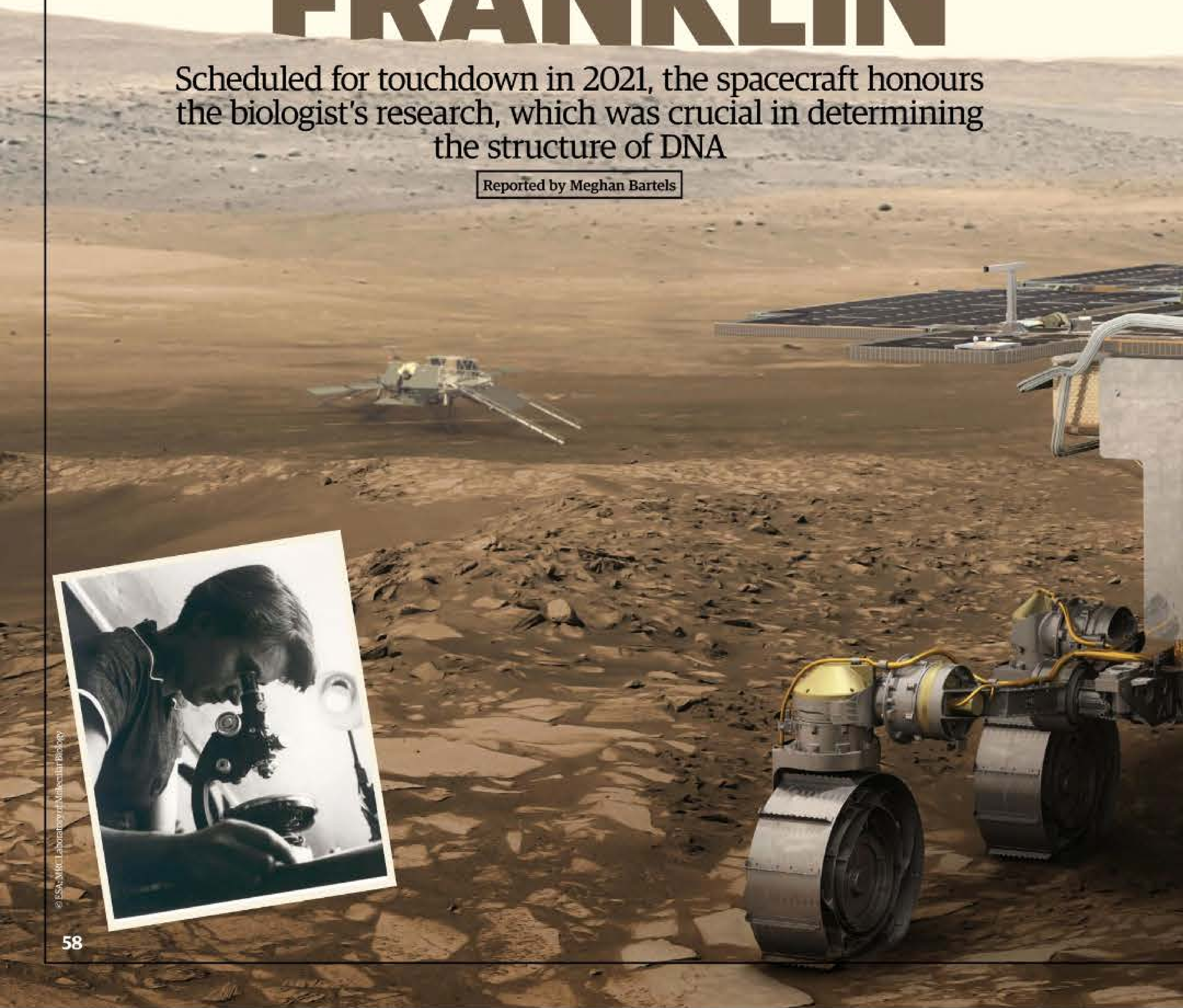
The pressures of a white dwarf star can result in interior crystals



EXOMARS ROVER NAMED FOR ROSALIND FRANKLIN

Scheduled for touchdown in 2021, the spacecraft honours the biologist's research, which was crucial in determining the structure of DNA

Reported by Meghan Bartels



© ESA, MRC Laboratory of Molecular Biology

The European Space Agency (ESA) has named its next Mars rover, due to touchdown on the Red Planet in March 2021, in honour of British scientist Rosalind Franklin, whose research was crucial to scientists in determining the structure of DNA.

Built in the United Kingdom, the rover is designed to search for traces of habitability and of life by roaming the Martian surface and drilling into the top two metres (6.5 feet) of the planet. If it successfully lands – never an easy feat with Mars' strong gravity and thin atmosphere – the Franklin rover would be Europe's first presence on the Red Planet's surface.

"Rosalind Franklin is one of science's most influential women, and her part in the discovery of the structure of DNA was truly groundbreaking," Alice Bunn, international director of the UK Space Agency, said in a statement. "It's fitting that the robot bearing her name will search for the building blocks of life on Mars, as she did so on Earth through her work on DNA."

In order to name the Franklin rover, which is part of the ExoMars series of missions and will succeed a failed lander called Schiaparelli, ESA pored through suggestions from 36,000 people. The agency chose to commemorate Franklin for her work as an X-ray crystallographer during the 1940s and 1950s. Franklin captured structural images of substances like viruses and coal, as well as the crucial biological compounds DNA and RNA, which both carry genetic information.

James Watson and Francis Crick used her research without permission and with little credit when publishing their model of the structure of DNA in 1953. In Watson's book *The Double Helix*, which shaped the narrative around the discovery of the structure of DNA for decades, he painted a vituperative picture of Franklin, whom he referred to as "Rosy". She died in 1958 at age 37, and her work went mostly unacknowledged until the 1990s.

"Rosalind the rover captures this spirit and carries us all to the forefront of space exploration," ESA director general Jan Wörner said in a statement. "This name reminds us that it is in the human genes to explore. Science is in our DNA, and in everything we do at ESA."

"The rover is designed to search for traces of habitability and of life by roaming the Martian surface"

Far left: British scientist Rosalind Franklin, whose research was crucial in determining the structure of DNA

Left: An artist's impression of the ExoMars rover

JAMES WEBB

WILL IT EVER LAUNCH?

Beset by delays and with costs rising, the government may pull the plug

Reported by David Crookes

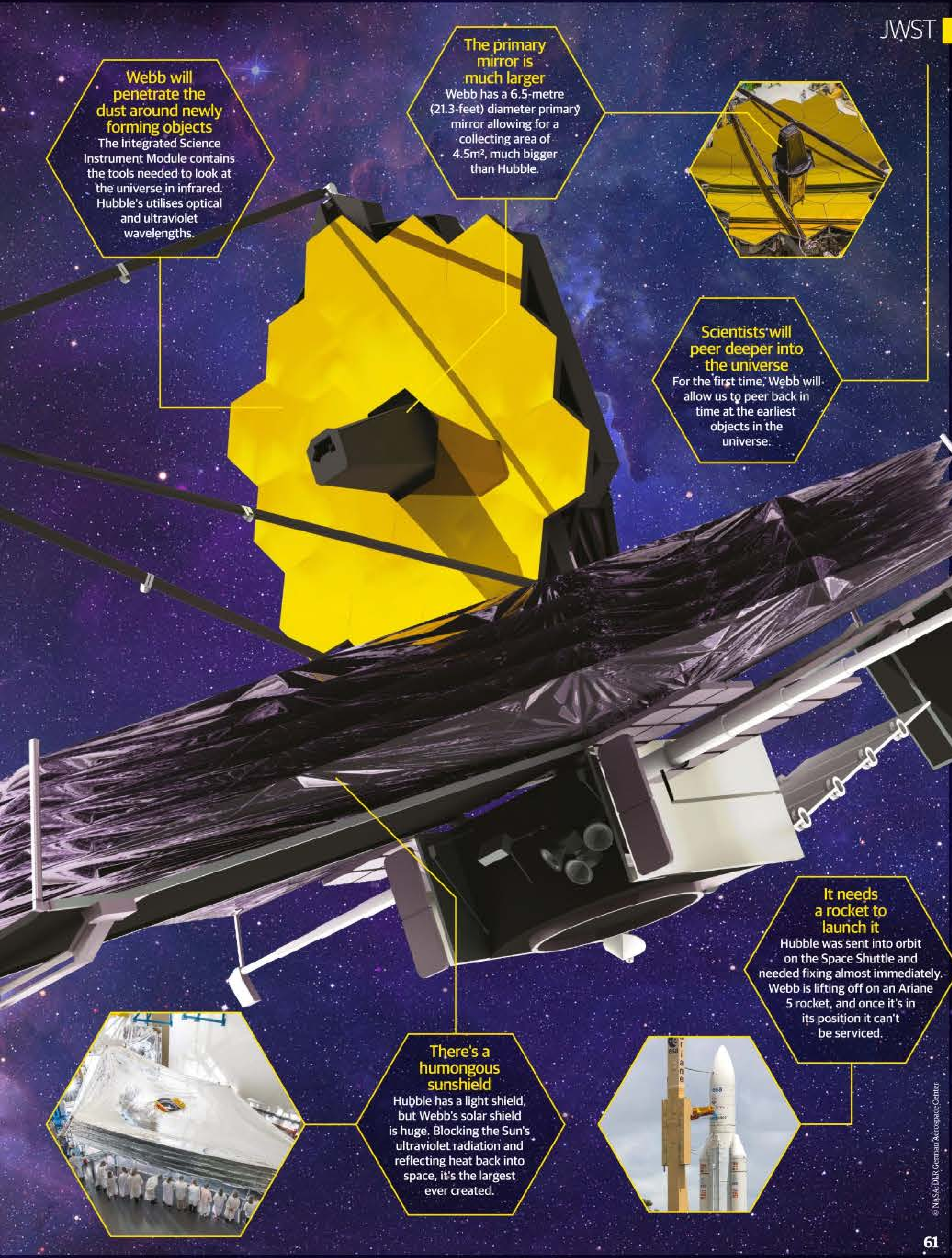
When NASA began work on its next-generation Space Telescope in 1996, six years after Hubble had been launched, there was great excitement among scientists that space was about to get ever closer.

Here was a plan to position a gigantic space observatory near the Earth-Sun L2 Lagrangian point, some 1.5 million kilometres (932,000 miles) away from Earth. With seven-times the light-collecting power of Hubble, it was envisaged it would be an advanced time machine of sorts, allowing astronomers to peer back like never before and uncover wonderful nuggets about our universe that, up until now, have frustratingly evaded us.

What nobody foresaw some 23 years ago, however, was just how distant those plans would become. In that time the complex structure that was renamed the James Webb Space Telescope (JWST) in 2002, after NASA's second administrator, has been beset with problems and delays. It still

Further away

Webb is not going to be orbiting the Earth. Instead it will be a staggering 1.5 million kilometres (932,000 miles) away.



Webb will penetrate the dust around newly forming objects

The Integrated Science Instrument Module contains the tools needed to look at the universe in infrared. Hubble's utilises optical and ultraviolet wavelengths.

The primary mirror is much larger

Webb has a 6.5-metre (21.3-feet) diameter primary mirror allowing for a collecting area of 4.5m², much bigger than Hubble.

Scientists will peer deeper into the universe

For the first time, Webb will allow us to peer back in time at the earliest objects in the universe.

It needs a rocket to launch it

Hubble was sent into orbit on the Space Shuttle and needed fixing almost immediately. Webb is lifting off on an Ariane 5 rocket, and once it's in its position it can't be serviced.

There's a humongous sunshield

Hubble has a light shield, but Webb's solar shield is huge. Blocking the Sun's ultraviolet radiation and reflecting heat back into space, it's the largest ever created.

© NASA; DLR German Aerospace Center

Below: NASA engineer Acey Herrera checks the copper test wires inside the thermal shield of the Mid-InfraRed Instrument

Right (clockwise): Engineers blast carbon dioxide snow at a test telescope mirror to clean it safely

The secondary mirror allows the telescope to form images that are accurate to less than a millionth of a inch

Taken in 2016, this photo shows 12 of the 18 flight mirror segments of the primary mirror having been installed

hasn't been launched, and the infrared-optimised telescope may not even get off the ground at all.

In many ways that sounds crazy, given the amount of time and effort that has already been invested. But, judging by the noises coming from the American government, the project will not be allowed to turn into a money pit. The JWST started with a budget of just $0.5 billion in 1996, but it has certainly snowballed since then. In 2001 the United States Congress rubber-stamped a pre-launch cap of $8 billion, yet costs have now smashed through that ceiling to $8.8 billion.

That has led to some alarm among America's top brass amid fears the costs could increase further. To that end NASA has been provided with $21.5 billion within the Commerce, Justice and Science spending bill, but while that includes $304,600,000 for JWST, an accompanying report expressed "profound disappointment with both NASA and its contractors regarding mismanagement, complete lack of careful oversight and overall poor basic workmanship". It was, in a nutshell, rather damning.

But just how has it come to this? If the report is to be taken at face value then "NASA and its commercial partners seem to believe that congressional funding for this project and other development efforts is an entitlement, unaffected by failures to stay on schedule or within budget". The truth, however, is much more complicated than a claimed lazy attitude, but NASA certainly has to tread carefully. Should it not adhere to the new cap of $8,802,700,000, "JWST will have to find cost savings or cancel the mission" and, for science, that would be devastating.

Had everything gone to plan, JWST would have launched by now. The original timeframe was October 2018, but it has slipped numerous times, first to spring 2019, then to May 2020 and now to March 2021 - a decision taken last June when it emerged there had been an acoustics test anomaly.

One of the big issues has concerned the use of a sunshield, one of the two vital components of this project - the other being the telescope itself. The sunshield is the size of a tennis court and is made up of a five-layer membrane, each one cooler than the one below. Composed of heat-resistant Kapton and coated with aluminium, their role is to deflect the Sun's light rays, allowing the mirrors to be kept below -220 degrees Celsius (-364 degrees Fahrenheit) and ensuring readings are not distorted.

Unfortunately this complex structure is also prone to tearing, as engineers have found to their - and the JWST's - cost. When they discovered the sunshield was unfurling, folding and stowing much more slowly than desired they also noted there was too much slack on the cables. The sunshield got caught on these, and it tore as much as ten centimetres (3.93 inches) of the material. There were seven rips in total and, as if that wasn't enough, there were also some leaky valves within the spacecraft's propulsion system to contend with.

Under normal circumstances problems such as these could be sorted after a telescope has been deployed, but JWST is going to be so far from Earth

> "Had everything gone to plan, JWST would have launched. The original timeframe was October 2018"

that sending robots on repair missions simply isn't an option. It's why problems are causing extremely lengthy delays – this is a one-shot mission. Should it go wrong once it's comfortably in position and the sunshield is unfurled, it really would spell the end.

That, of course, would be a real shame for science. JWST comprises 18 hexagonal segments that make up a 6.5-metre (21.3-feet) primary mirror made of beryllium, making it powerful enough to be able to peer at some of the first stars and galaxies which appeared in the universe. What's more, the telescope will also give a greater insight into potential signs of life in the atmospheres of nearby exoplanets. Able to observe from visible red/orange to mid-infrared, it can pick up on high-redshift objects. But none of that will be possible if it remains on the ground.

Luckily there is a great desire to see it lift off. NASA administrator Jim Bridenstine said: "Webb is vital to the next generation of research beyond NASA's Hubble Space Telescope. It's going to do amazing things – things we have never been able to do before – as we peer into other galaxies and see light from the very dawn of time."

It was also heartening that the Independent Review Board (IRB), as recently as July, recommended development should continue. Thomas Zurbuchen, associate administrator of NASA's Science Mission Directorate, said it meant JWST's total lifecycle cost is now likely to top $9.66 billion, but he drew attention to the "exceptional potential and science insight" the telescope will promise.

"Webb's world-class science," he wrote, "will underpin many other astrophysics projects that will use its high-calibre capabilities to enhance their science return." And yet there remains a need to step up a gear. The telescope's primary contractor Northrop Grumman came under fire when it emerged human error caused the wrong solvent to be used when cleaning a fuel valve. Excessive voltage was also applied to transducers thanks to incorrect wiring: mistakes that racked up the price and caused delays.

The IRB also drew attention to the complexity of the systems, a lack of experience in areas such as sunshield development, embedded problems and excessive optimism. It has become clear that NASA didn't really have a handle on the costs from the start, but that has tended to be the case with such things. Indeed, Hubble cost six-times the original projection of $200 million.

NASA, however, must now take on a greater role in overseeing the project and check test reports daily and weekly. The good news is that all of the technologies needed for the project have now been invented – something that wasn't the case at the start – so the project should from this point on be purely about perfecting the systems.

It is also worth bearing in mind that, even at $8.8 billion, the telescope is something of a bargain for the results it should bring. In the fourth quarter of the fiscal year 2018 Apple raked in $62.9 billion from the sale of iPhones alone: and, try as you may, you'll never detect light from the first stars and galaxies using one of those.

THE DEBATE

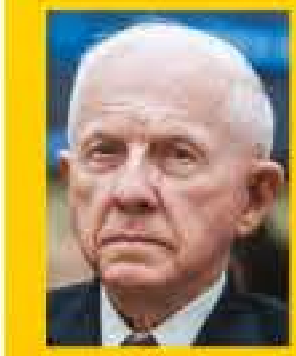
Will James Webb launch within five years?

"Webb is critical to answering questions we didn't even know how to ask when the spacecraft was first designed. Webb is worth the wait."

Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate

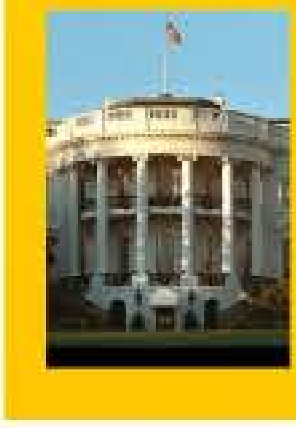
"We have to be better as an agency at accountability and making sure that we are either awarding or properly incentivising our contractors to deliver on time and on budget."

Jim Bridenstine, the administrator of NASA



"Webb should continue based on its extraordinary scientific potential and critical role in maintaining US leadership in astronomy and astrophysics."

Tom Young, chair of the JWST Independent Review Board



"NASA should strictly adhere to this cap [of $8,802,700,000] or, under this agreement, JWST will have to find cost savings or cancel the mission."

Report accompanying a Commerce, Justice and Science Spending Bill

© NASA; Tom Williams / Getty

JAPAN SNATCHES ITS ASTEROID SAMPLE

Hayabusa2 has successfully scooped up some 'dirty snowball'

Words by **Mike Wall**

The Hayabusa2 spacecraft, which has been studying the near-Earth asteroid Ryugu up close since last June, has made its first sample-grabbing dive.

February's operation was originally scheduled to take place in October, but mission team members delayed the activity to give themselves more time to take stock of Ryugu's unexpectedly complex and rugged surface.

Hayabusa2 will make two additional sample-grabbing sorties after this month's activity, including one trip to snag material from a fresh crater. The spacecraft will create this crater itself by sending a 'kinetic impactor' barrelling into Ryugu.

The various bits of Ryugu material will travel to Earth in a special return capsule in December 2020, if current schedules hold. Scientists around the world will then study the cosmic dirt and gravel, looking for clues about the Solar System's early history and the role that carbon-rich asteroids like Ryugu may have played in life's emergence on Earth.

The mission has already touched Ryugu's surface multiple times. The Hayabusa2 mothership deployed two tiny, hopping rovers onto the space rock last September, dropping a European-built lander called MASCOT onto the asteroid less than two weeks later.

Hayabusa translates from Japanese as 'Peregrine Falcon'

Snapshots of a space rock

© JAXA/Akihiro Ikeshita

ON SALE NOW!

HONOR VIEW 20 REVIEW: NO MORE NOTCH
T3
SMARTER LIVING
2019'S TOP TECH
GADGET WISHLIST
40 buys to supercharge your world
Amazing tech from £59 to £8k
New Dolby Atmos, Alexa kit & more
WORLD FIRST
ROLLABLE OLED TV
Meet the most futuristic set ever
HOT NEW 8K TVs
TESTED
HI-FI STREAMING SPEAKERS
Incredible sound, next-gen tech
DITCH THE LAPTOP!
Souped-up tablets from Apple, Google and Microsoft are ready to muscle out your notebook
TOP 6
Fitness trackers for newbies
5G GUIDE
It's coming! Here's what you need to know

Available at **WHSmith**, myfavouritemagazines.co.uk
or simply search for 'T3' in your device's App Store

SUBSCRIBE TODAY AND SAVE!
www.myfavouritemagazines.co.uk/T3

GET IT ON Google play · zinio · Available on the App Store

©Tobias Roetsch

> "For anything that varies, TESS can shed light on it, and it teaches us more about things at all scales in the universe"

SUPER-EARTH DISCOVERY

"WE WONDERED WHY IT WASN'T FOUND A DECADE AGO"

Dr Diana Dragomir tells us more about an exoplanet found by NASA's Transiting Exoplanet Survey Satellite (TESS) and what makes it one of the most exciting worlds we've uncovered to date

Interviewed by Lee Cavendish

Congratulations on your discovery of HD 21749b! How does it feel to be one of the first to discover an exoplanet with the new TESS data?

It's pretty cool. I think we are expecting many, many more things to come, but yes, it's nice. I think it's nice to be a part of the dawn of TESS, and I'm excited for what's coming next from all the other astronomers.

So how does TESS compare with NASA's previously launched Kepler Space Telescope?

So Kepler had about a metre [three-foot] aperture, while the four cameras on TESS are ten centimetres in diameter. So it is quite a bit smaller, but they were each designed to do different things.

Kepler was designed to stare at one part of the sky for three or more years and find transits of exoplanets in that part of the sky, going into periods as long as possible. The idea was that an Earth-like planet will have an Earth-like orbit of one year, and you will only see one transit around the star once every year. If you look away you might not see a transit, and if you want to be sure it's really there, then you might want to see three transits. That's what Kepler wanted to do. So you really need to stare for at least three years in order to see three transits of an Earth analogue.

TESS wants to find planets orbiting stars much closer to us. For that reason it's doing a scan of the entire sky to look for planets, especially around stars close to us because they're brighter and easier to study. It's observing the sky by staring at a strip of sky for 27 days at a time and then moving to the next strip. You can imagine these strips as being like orange slices, but rectangular so they don't get narrow at the top of the hemisphere.

Stars that are near the ecliptic poles and in the rectangular strips in which TESS observes - which we call sectors - actually overlap near the poles. That means that any star there gets observed for more than 27 days. It's a pretty small patch of sky that gets that, but it's going to be a pretty valuable patch of sky because we can get longer period planets in that area.

Can you tell us a bit more about HD 21749b and how you came to discover it?

Yes, sure! So I mentioned the stars near the ecliptic poles where TESS can actually observe those stars for longer than 27 days, and I mentioned that for a reason because that's what happened with this exoplanet.

MIT releases the data in batches and sectors, so when this planet candidate was announced to the astronomical community it was released together with two sectors of data - so 54 days. In those 54 days there was only one transit. That got me really excited because, on the one hand, one transit is really difficult to study because you don't know the period for the planet until you get another transit.

INTERVIEW BIO

Dr Diana Dragomir

Diana Dragomir is a Hubble Fellow at the Massachusetts Institute of Technology (MIT) in the United States, the same institute that leads operations of NASA's Transiting Exoplanet Survey Satellite (TESS) space telescope. Diana's research topics are heavily focused on the characterisation of 'small' exoplanets, which are exoplanets smaller than Neptune.

She has recently announced the discovery of HD 21749b, a sub-Neptune exoplanet orbiting a K-type dwarf star just 16 light years away, which was one of first three exoplanets to be found using new TESS data.

But, at the same time it means that it probably has a long period. So if we could get another transit and measure the period then that's great - we have a long-period planet, which are usually harder to find.

We found this long transit and because it was around a very bright star we thought: 'OK, let's see if someone else has observed this star with what we call the radial velocity method.' This is spectroscopy that measures the motion of the star in response to the motion of planets around it. It's also known as the stellar wobble.

We looked at existing public data from years ago and we found a signal in this data that had a period of about 35 days. We first wondered why someone didn't publish this planet a decade ago when they first observed it. It turns out that the star was a little bit active. It had spots on it and it was believed that the rotational period of the star was also around 35 days. So the scientists that first looked at the data didn't want to jump to conclusions and dropped the star because they could have just been looking at spots on the surface of the star.

That's all good... that's how science works. I'm always happy to be more cautious, but then we have this long transit, and I'm like: 'OK, well this gives us a bit more confidence that the signal in the wobble data is actually a real planet.' If it was true, then we expected another transit approximately 35 days later.

Then another sector of TESS data was released and that's where the second transit should have happened, if indeed the wobble data was correct. We looked and there was actually a gap right where the transit was expected, and that was frustrating at first, but there is another planet I found by digging through the data... and I'm stubborn. So I went back to the raw data to see for myself and I realised a lot of the gap was because TESS did not observe during that couple of hours. However there was a little bit of data at the end of the gap that seemed to show the end of a transit.

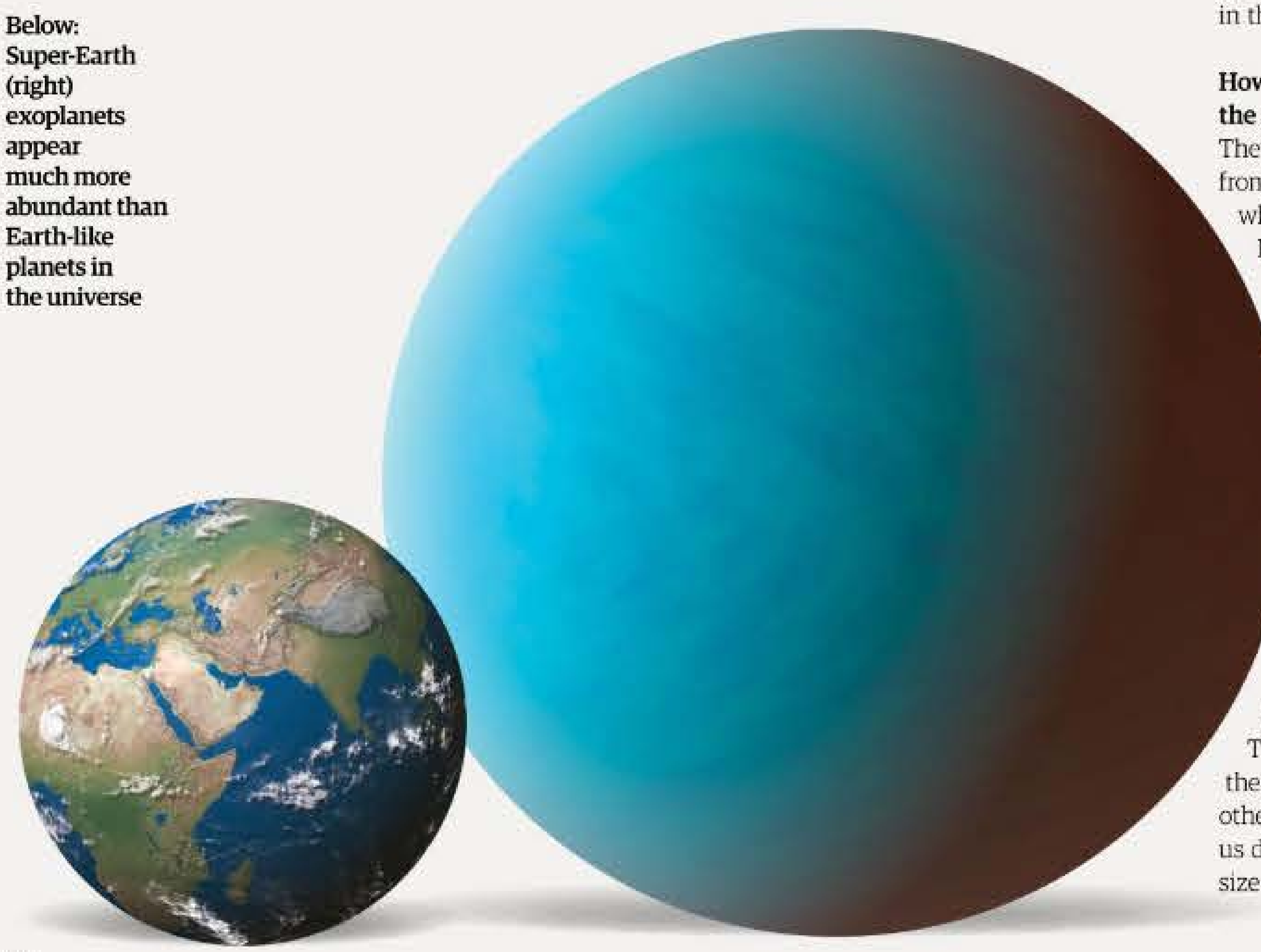
I went to my colleague, Chelsea Huang, who is an expert on this and she told me, "No, no, no. That's just bad data. You shouldn't trust it. It's right after the gap, who knows what happened." And I'm like, "No! But look! It really matches the first transit." It had the same depth; it had the same shape - even though it's only part of it. Let's go back to the original data and pull it out more carefully to see if it's real. We did that and turns out it was real. So that's the bottom line, but it did take some digging.

What do we know about HD 21749b?

From the transit we can measure the size of the planet, especially if we know the size of the star. In particular, this star is actually what we call a K-dwarf star. It's not a yellow star like the Sun or a red dwarf like the M-dwarf stars that everyone seems to be finding planets around lately. This was an orange dwarf [star] about 0.7-times the size of the Sun and about 0.7-times the mass of the Sun.

Now this planet around it in itself is about three-times the size of Earth, which makes it a bit bigger than Earth but smaller than Neptune and Uranus.

> "The big value of this system is we can study the exoplanet - and its star - in great detail and actually learn more about it"



Below: Super-Earth (right) exoplanets appear much more abundant than Earth-like planets in the universe

© NASA/JPL-Caltech; Orbital ATK

Because we have the wobble data we were also able to measure the mass of the planet. With the radius and the mass known, we can obtain the density. The mass of the planet is 23 Earth masses. From this we discovered the planet has a density of 5.7 grams per centimetre cubed, which doesn't mean much by itself. However, we know from our models that it indicates a planet that is not so dense that it's rocky like Earth, but it's also not so low in density, or 'puffy', that it would be like Neptune. So it's somewhere in between.

Is there a way of uncovering more about it?

It would be interesting to try and learn more about its atmosphere with upcoming telescopes such as the James Webb Space Telescope. We may also be able to use ground-based telescopes like the Extremely Large Telescope that the Europeans are building.

Until then we may not learn too much about its atmosphere because when the atmosphere is shallow or not very high, it's harder to probe because less light from the star goes through it and we gets less signal.

We understand that there is something special about this exoplanet's temperature. Can you shed some light on that?

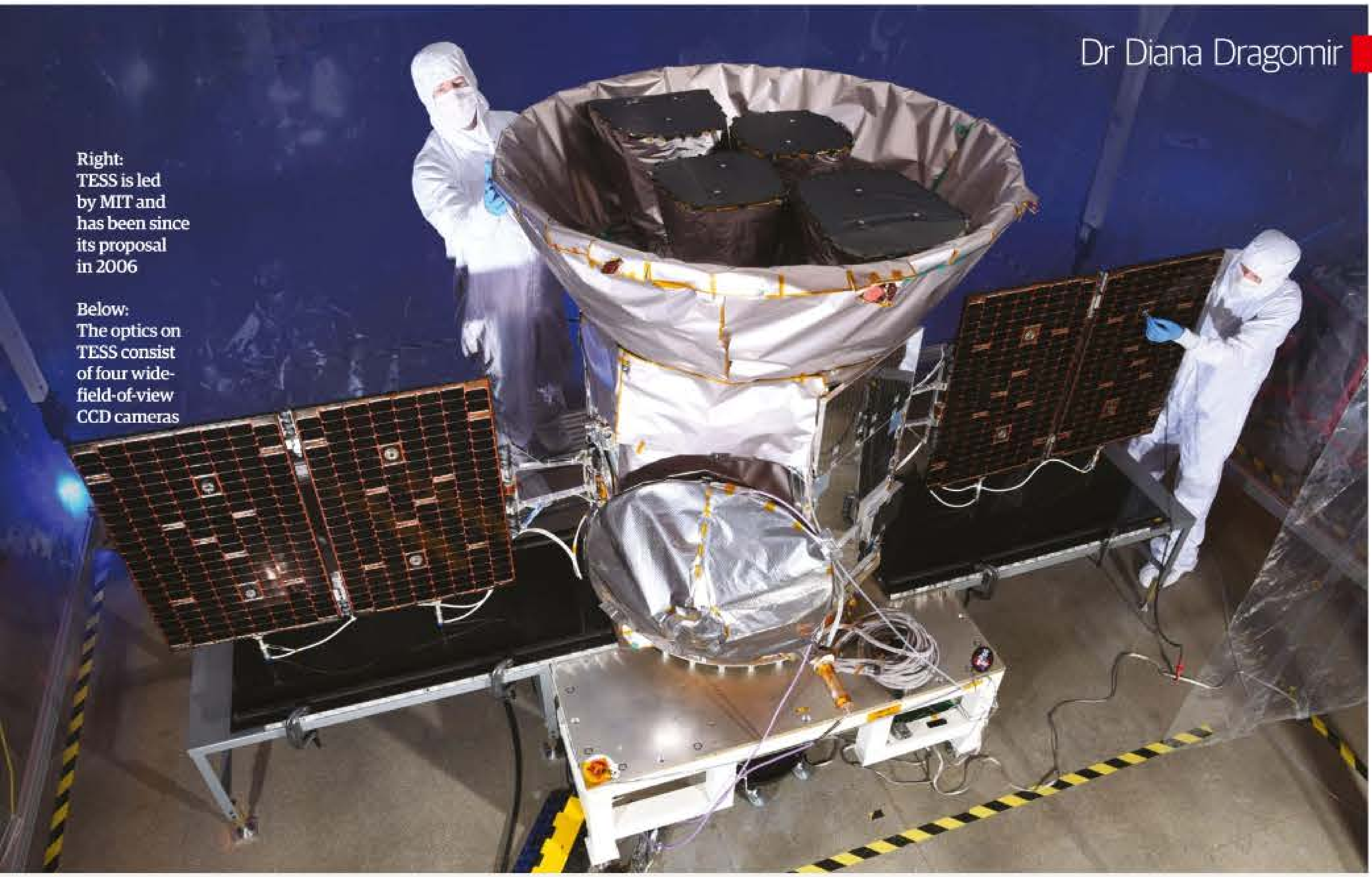
This exoplanet is potentially very interesting because this is the coolest, or rather the lowest temperature, planet we know of around a star this bright. It's around 150 degrees Celsius (300 degrees Fahrenheit), which is hotter than the boiling point of water. It's not as cool as Earth, but it's one of the cooler ones we know of. The big value of this system is we can study the exoplanet - and its star - in great detail and actually learn a bit more about it than just its size and mass. In that sense I think a lot of atmospheric accurisation astronomers will be interested in seeing what kind of compounds exist in the atmosphere of this rather cooler planet.

How common are these exoplanets around the universe?

They're pretty common. One really fantastic result from Kepler was that these small planets - and when I say 'small', I arbitrarily mean smaller than Neptune basically - tend to be very common in the Milky Way, at least out to periods that we have been able to probe. So about 50 days.

In that sense, a planet the size of this one is not very uncommon. Again, the really nice thing here is that it's really close to us and we can study it, but we know that they're pretty common thanks to Kepler and we've been waiting a really long time for one that is close enough that we can actually learn a bit more about it.

The other really exciting thing about this planet, and these other planets that are really common, is that a lot of them have a size that is in between that of Earth and Neptune. There are no super-Earths and mini-Neptunes in the Solar System, which is frustrating because ever other star seems to have at least one! But this helps us determine the size regime. A planet twice the size of the Earth, for example: is it going to be rocky,



Right:
TESS is led by MIT and has been since its proposal in 2006

Below:
The optics on TESS consist of four wide-field-of-view CCD cameras

or is it going to be more like a mini gas giant? What size does that transition happen?

Maybe the answer is more complicated. Maybe it depends on the [host] star or where the planet formed and the composition of the star itself, because that says something about the composition of the initial molecular cloud that also formed the planet. We don't know. Being able to measure all these things is going to help us answer questions about what the heck these super-Earths and sub-Neptunes are like.

So will your future efforts be focused on trying to understand HD 21749b more, or going back to TESS data to try and find more exoplanets?

A bit of both. I have some colleagues that are interested in measuring the inclination of the orbit. But I am interested in its atmosphere, so when the James Webb Space Telescope launches I will think about what onboard instruments I can use to look at its atmosphere. Beyond that, there's another small planetary candidate in the same system. I'm interested in trying to confirm that one and make sure that it is indeed in the same system - that would be exciting in its own right because it would be an Earth-sized planet. So I'm making it my homework to confirm. If it's not confirmed, then it's not confirmed. So be it. That's science.

After that, I think yes, I would like to keep finding more planets than this. That would be my main goal because one of my research avenues, so to speak, is to build up statistics of these small planets.

We understand TESS will be studying more than just exoplanets. Can you tell us a bit more about what else the space telescope will be looking at?

Because TESS is staring at patches of the sky and taking images of that entire patch of the sky for 27 days, it's looking for anything that can vary [in brightness] in the sky. Yes - transiting exoplanets is one type of variability to watch out for, but it can do so much more. It can do stellar variability and look at how spots affect the surface of the star, which can also have implications for studying exoplanet atmospheres.

Then, going even bigger, TESS is discovering - and observing for up to 27 days - supernovae! That is something you cannot do from the ground because there is a day-night cycle, so it's actually really hard to observe them continuously. Even though it [TESS] is a small telescope it can provide time coverage of supernovae, which can be really useful in conjunction with data obtained from the ground with larger telescopes. You get a more complete picture of the star that made the supernova - what it was like - and determine if it's a particularly exciting supernova, or if it's a standard supernova.

The same thing goes for active galactic nuclei and black holes, both of which show variability in the optical wavelength. Having a 27-day time series of how these things are varying is a luxury that we can't afford from the ground. In that sense, TESS is really opening a window into what we call the 'transient universe'. For anything that varies, TESS can shed light on it and, together with observations from the ground, it teaches us more about things at all scales in the universe.

Instant Expert

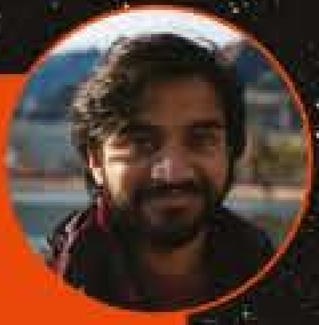
Redshifting galaxies explained

What does it mean when an astronomical object is redshifted? **All About Space** has found the perfect astronomer to reveal all

Ever noticed how the sound of an ambulance siren changes in pitch as it is approaching or going away from us? The pitch becomes higher when a sound-emitting object is coming towards us, and the pitch becomes lower when it is moving away from us. This phenomenon is called the Doppler effect, named after the Austrian physicist Christian Doppler who first described it in 1842. The Doppler effect manifests itself as a perceived change in the wavelength, or frequency, of sound waves – the wavelength is shortened (higher frequency) when an object approaches an observer, and the wavelength is lengthened (lower frequency) when an object moves away from an observer.

In a similar way, the wavelengths of light waves undergo Doppler shifting too. Objects moving away seem to have longer or redder wavelengths, and objects moving towards us have shorter or bluer wavelengths. This shifting is extensively used in astronomy to estimate the speeds and distances of galaxies by measuring how much their light has been 'blueshifted' or 'redshifted'.

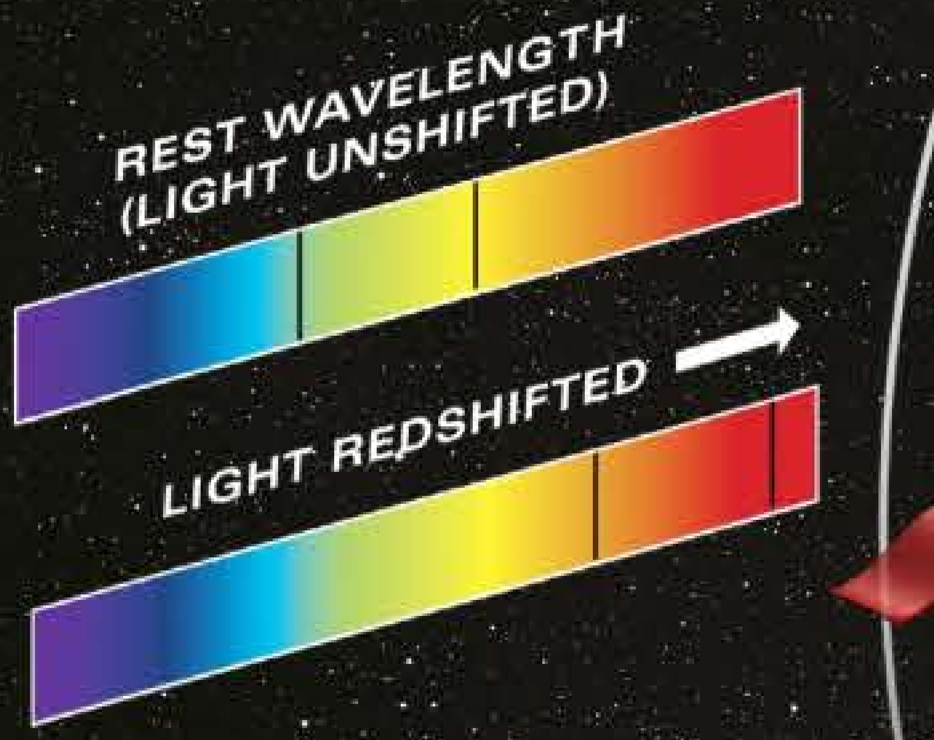
To estimate this shift astronomers rely on observations of known features in the light emitted by a galaxy. For example, scientists know from controlled laboratory experiments the exact wavelength at which strong emission lines are emitted by atoms such as hydrogen or oxygen when completely at rest. When the emission lines from galaxies are observed using spectroscopy, a process that splits light coming from an object into a spectrum of wavelengths, astronomers can spot features that look similar to those from known atoms. Once the spectral features have been confirmed the 'observed' wavelengths of the emission lines can be compared with the laboratory 'rest-frame' wavelengths, and a 'shift' can be measured. This shift is then used to infer whether a galaxy is moving towards or away from us, and at what speed.



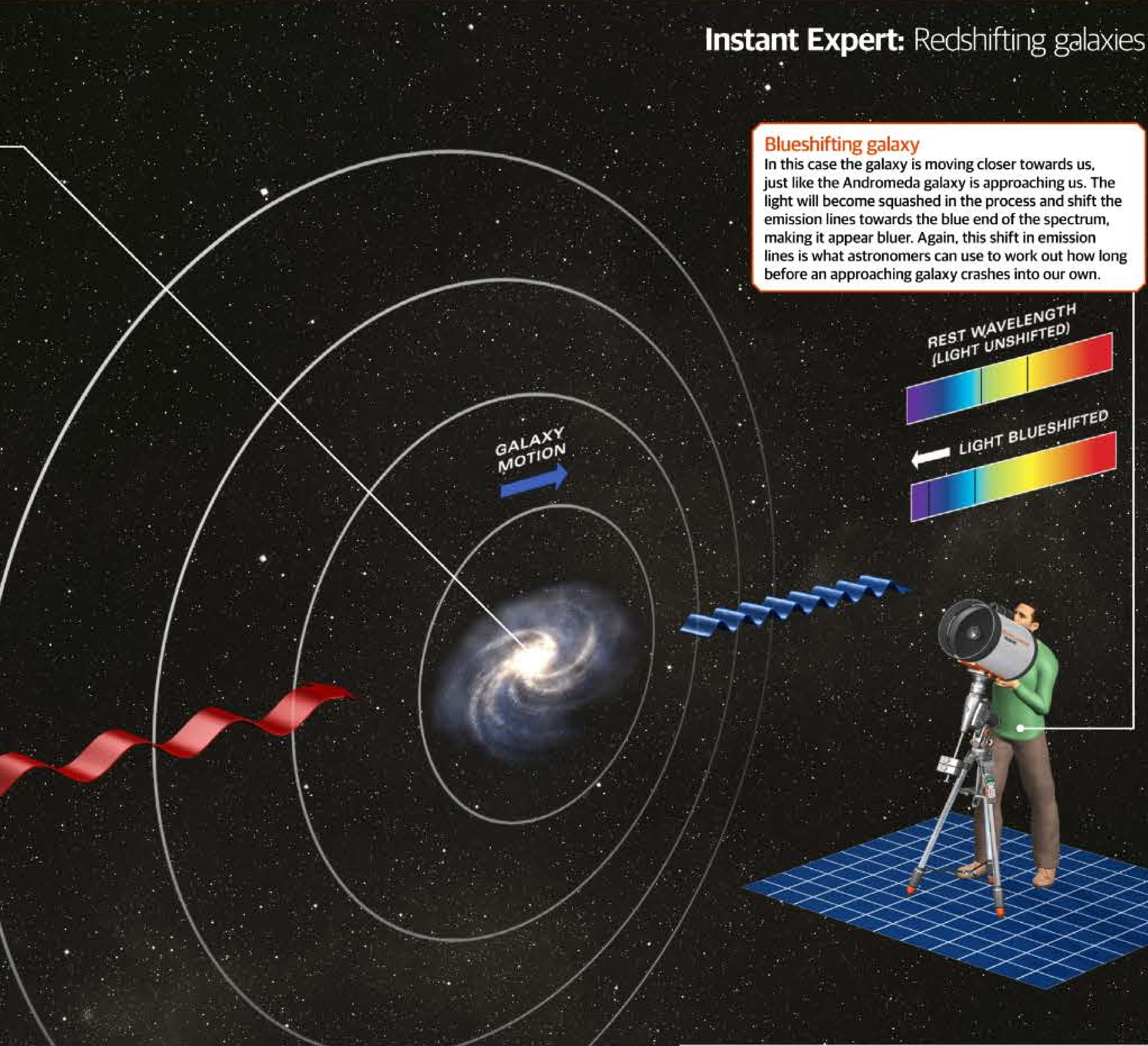
BIO
Dr Aayush Saxena
Saxena is a postdoctoral researcher in Astronomy and Astrophysics at Leiden Observatory in the Netherlands. His research revolves around the most distant and most massive galaxies in the universe.

> "Objects moving away seem to have longer or redder wavelengths, and towards us have shorter or bluer wavelengths"

The galaxy at rest
Astronomers will be able to identify the simplest elements in a galaxy, such as hydrogen and oxygen. Thanks to laboratory analysis scientists can also deduce what the rest of the emission lines of these elements would look like when a galaxy is at rest. This is used as a frame of reference when deducing the motion of a galaxy.

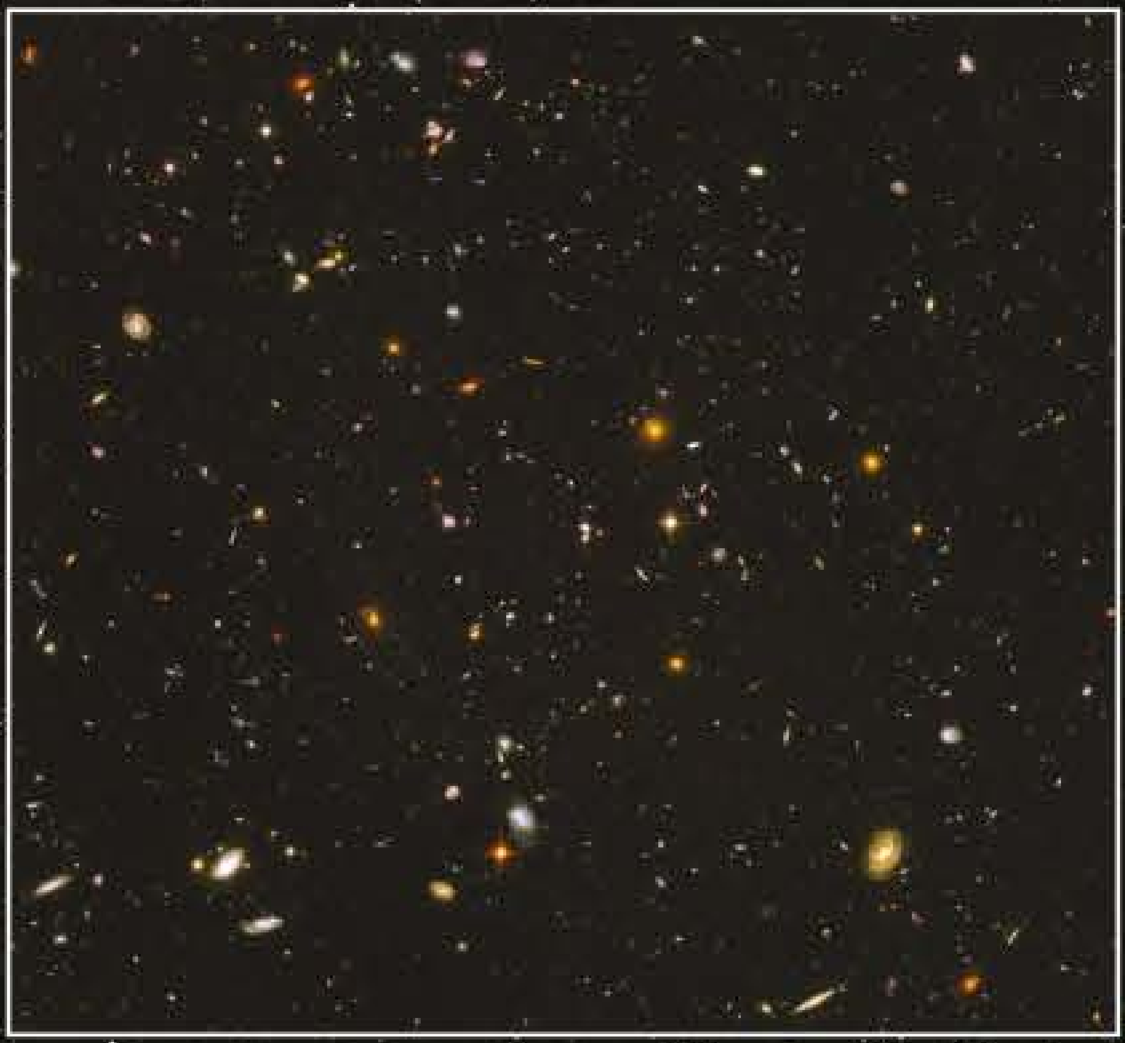


Redshifting galaxy
If the galaxy is moving away from us then its light will be stretched, making the light appear redder. This motion will also cause emission lines in the galaxy's spectra to be shifted towards the red end of the spectrum. This is the difference that scientists can measure in order to accurately determine how fast the galaxy is moving away from us.



Blueshifting galaxy

In this case the galaxy is moving closer towards us, just like the Andromeda galaxy is approaching us. The light will become squashed in the process and shift the emission lines towards the blue end of the spectrum, making it appear bluer. Again, this shift in emission lines is what astronomers can use to work out how long before an approaching galaxy crashes into our own.



Right: Some of the galaxies in the Hubble Ultra-Deep Field appear redder due to being redshifted

©NASA/ESA; Carlos Clarivan / Science Photo Library

STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

In this issue...

72 What's in the sky?
Make the most of the last set of longer nights with a selection of observational targets

76 Planets on display
Venus, Jupiter and Saturn shine bright together before dawn, while Mars rules the evening

78 Moon tour
Posidonius lies on the northeast of Mare Serenitatis and has interesting features on its floor

79 Naked eye and binocular targets
Split Mizar and Alcor - the Big Dipper's double

80 Galaxy tour
Spring is a great time to seek out the galactic treasures of Leo, Virgo and Ursa Major

86 How to... Use Stellarium
Our guide to one of the best planetarium programs available

88 Deep sky challenge
What lies hidden among the stars of 'the King' of constellations?

90 The Northern Hemisphere
The Great Bear and its treasures sparkle overhead

92 Astrophotos of the month
The best of our readers' astrophotography

96 In the shops
Our pick of the best books, apps, software and accessories for astronomy and space fans

What's in the sky?

1 MAR
The Moon and Saturn make a close approach, passing within 0°18' of each other in Sagittarius

3 MAR
Theta Carinae open cluster (IC 2602) is well placed for observation in Carina at magnitude 1.9

11 MAR
Conjunction between the Moon and Mars in Aries

17 MAR
The Moon and the Beehive Cluster (M44) pass within 0°09' of each other in Cancer

18 MAR
Comet 69P/Taylor makes a close approach in Taurus, predicted to reach magnitude 12.7

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

© Miguel Garcia

22 MAR
Conjunction between Mercury and Neptune in Pisces and Aquarius

Red light friendly
In order to preserve your night vision, you should read our observing guide under red light

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

1 MAR

Conjunction between the Moon and Saturn in Sagittarius

© Brocken Inaglory

2 MAR

Conjunction between the Moon and Venus in Capricornus

2 MAR

The Moon and Venus make a close approach within 1°11' of each other in Capricornus

9 MAR

Open star cluster NGC 3532 is well placed for observation in Carina, glowing at magnitude 3

© ESO

20 MAR

March equinox

© Cr1963

25 MAR

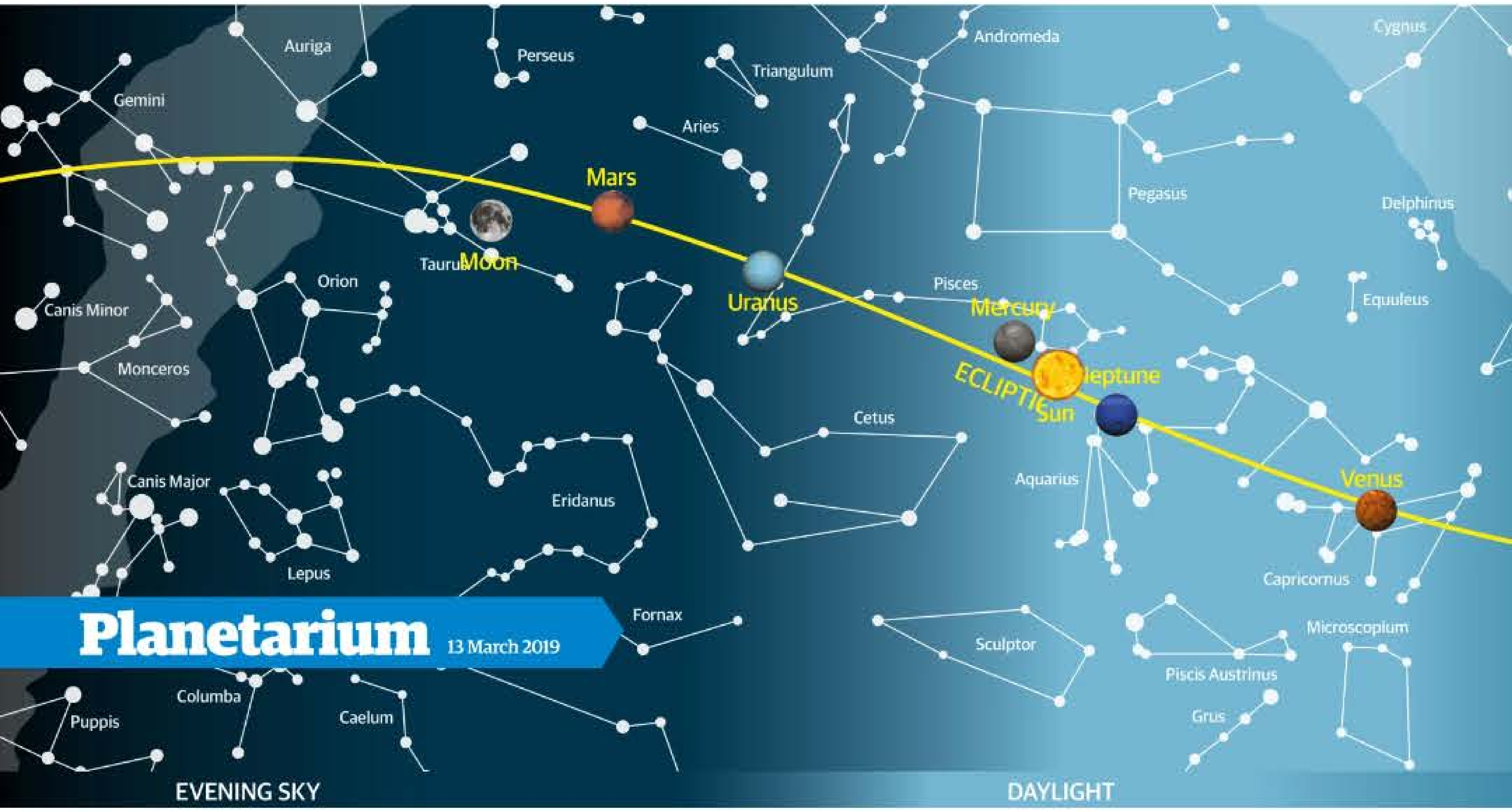
Dwarf planet Makemake reaches opposition in Coma Berenices at magnitude 17.1

27 MAR

Conjunction between the Moon and Jupiter in Ophiuchus

27 MAR

The Moon and Jupiter make a close approach, passing within 1°52' of each other in Ophiuchus



Planetarium

13 March 2019

Moon calendar

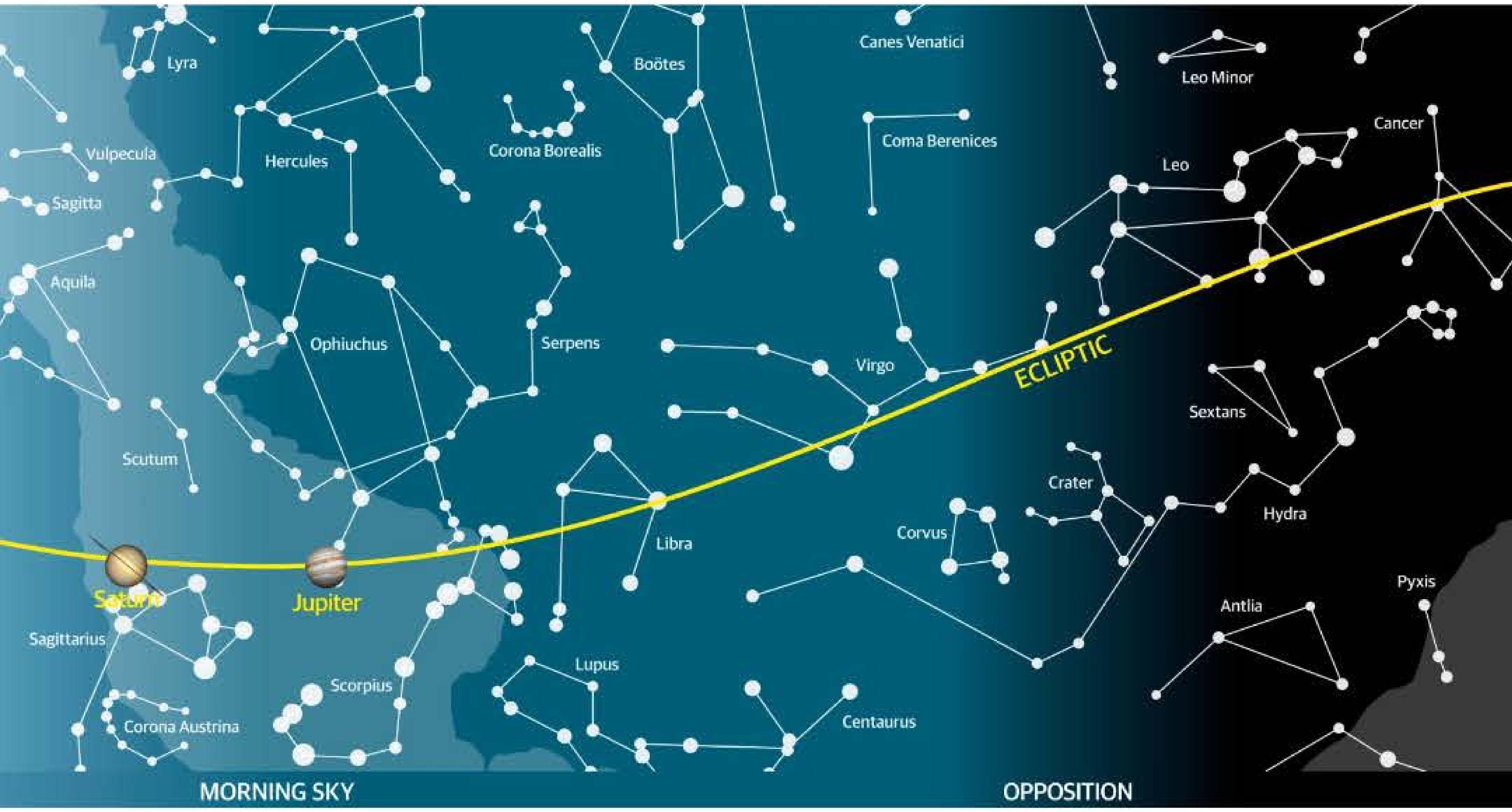
* The Moon does not pass the meridian on 20 March

			27 FEB 42.1% ▲02:17 ▼10:59	**28 FEB** 32.3% ▲03:18 ▼11:40	**1 MAR** 23.3% ▲04:12 ▼12:28	**2 MAR** 15.6% ▲04:58 ▼13:22
3 MAR 9.2% ▲05:36 ▼14:21	**4 MAR** 4.4% ▲06:08 ▼15:24	**5 MAR** 1.4% ▲06:34 ▼16:28	**6 MAR** NM 0.1% ▲06:57 ▼17:34	**7 MAR** 0.8% ▲07:18 ▼18:40	**8 MAR** 3.5% ▲07:37 ▼19:46	**9 MAR** 8.1% ▲07:56 ▼20:54
10 MAR 14.5% ▲08:16 ▼22:02	**11 MAR** 22.5% ▲08:38 ▼23:12	**12 MAR** 31.9% ▲09:03 ▼--:--	**13 MAR** 42.5% ▼00:23 ▲09:34	**14 MAR** FQ 53.8% ▼01:33 ▲10:13	**15 MAR** 65.2% ▼02:40 ▲11:03	**16 MAR** 76.1% ▼03:39 ▲12:04
17 MAR 85.7% ▼04:30 ▲13:17	**18 MAR** 93.2% ▼05:12 ▲14:38	**19 MAR** 98.1% ▼05:46 ▲16:02	**20 MAR** *--.-% ▼06:14 ▲17:27	**21 MAR** FM 99.8% ▼06:40 ▲18:51	**22 MAR** 98.4% ▼07:04 ▲20:14	**23 MAR** 94.1% ▼07:27 ▲21:34
24 MAR 87.5% ▼07:53 ▲22:50	**25 MAR** 79.1% ▼08:22 ▲--:--	**26 MAR** 69.6% ▲00:03 ▼08:55	**27 MAR** 59.5% ▲01:09 ▼09:34			

% Illumination
▲ Moonrise time
▼ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage

	6 MAR	13 MAR	20 MAR	27 MAR
MERCURY	20%	0%	0%	20%
VENUS	70%	80%	80%	80%
MARS	90%	90%	90%	90%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

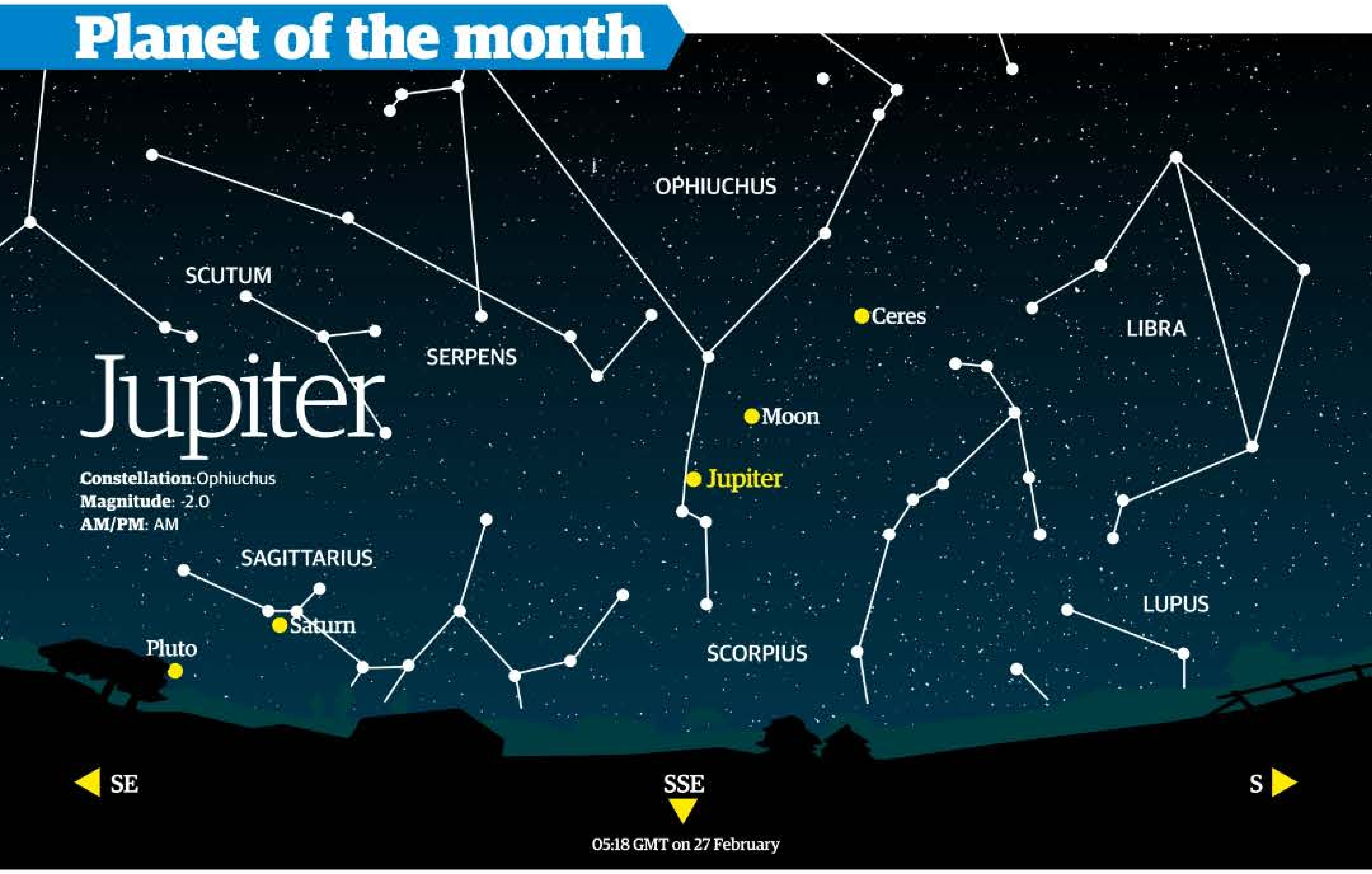
All rise and set times are given in GMT

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	27 Feb	23h 42m 38s	-00° 16' 00"	Pisces	-0.5	07:21	19:26
	06 Mar	23h 52m 53s	+02° 32' 41"	Pisces	1.2	06:48	19:24
	13 Mar	23h 38m 56s	+01° 40' 02"	Pisces	4.8	06:11	18:37
	20 Mar	23h 16m 52s	-01° 42' 37"	Pisces	3.7	05:40	17:29
	27 Mar	23h 06m 47s	-04° 39' 11"	Pisces	1.5	05:19	16:36
VENUS	27 Feb	19h 53m 31s	-19° 53' 34"	Sagittarius	-4.1	05:28	13:41
	06 Mar	20h 28m 14s	-18° 33' 07"	Capricornus	-4.1	05:26	13:57
	13 Mar	21h 02m 29s	-16° 46' 48"	Capricornus	-4.0	05:21	14:16
	20 Mar	21h 36m 08s	-14° 37' 10"	Capricornus	-4.0	05:14	14:35
	27 Mar	22h 09m 10s	-12° 07' 18"	Aquarius	-4.0	05:04	14:56
MARS	27 Feb	02h 22m 29s	+14° 50' 20"	Aries	1.2	08:34	23:32
	06 Mar	02h 40m 56s	+16° 22' 58"	Aries	1.2	08:15	23:32
	13 Mar	02h 59m 37s	+17° 49' 09"	Aries	1.3	07:56	23:33
	20 Mar	03h 18m 31s	+19° 08' 14"	Aries	1.4	07:38	23:34
	27 Mar	03h 37m 38s	+20° 19' 39"	Taurus	1.4	07:21	23:34
JUPITER	27 Feb	17h 22m 37s	-22° 32' 01"	Ophiuchus	-2.0	03:17	10:51
	06 Mar	17h 26m 02s	-22° 34' 50"	Ophiuchus	-2.1	02:53	10:27
	13 Mar	17h 28m 54s	-22° 36' 57"	Ophiuchus	-2.1	02:29	10:02
	20 Mar	17h 31m 12s	-22° 38' 29"	Ophiuchus	-2.2	02:04	09:37
	27 Mar	17h 32m 53s	-22° 39' 30"	Ophiuchus	-2.2	01:38	09:11
SATURN	27 Feb	19h 14m 47s	-21° 53' 20"	Sagittarius	0.6	05:04	12:48
	06 Mar	19h 17m 20s	-21° 49' 00"	Sagittarius	0.6	04:39	12:24
	13 Mar	19h 19m 38s	-21° 44' 57"	Sagittarius	0.6	04:13	11:59
	20 Mar	19h 21m 39s	-21° 41' 18"	Sagittarius	0.6	03:47	11:34
	27 Mar	19h 23m 25s	-21° 38' 06"	Sagittarius	0.6	03:21	11:08

This month's planets

Jupiter rules the morning skies this March, while other members of the Solar System take the night watch

Planet of the month



Jupiter

Constellation: Ophiuchus
Magnitude: -2.0
AM/PM: AM

05:18 GMT on 27 February

If you have binoculars you should definitely point them towards Jupiter this month. Although the planet is enormous it is too far away for binoculars to reveal its disc, but they will show you some of its extended family of moons. It has been said many times that Jupiter is like a miniature Solar System orbiting the Sun because of its large number of moons; at the last count it had 79 moons in orbit around it. Many are really small, but the four largest - known as the Galilean Satellites because they were discovered by Galileo in 1610 with his first crude telescopes - are the size of our own Moon, and these can be seen through binoculars as tiny silvery stars close to Jupiter. They change their arrangement every night, but there are lots of apps you can download to your tablet or phone to help you identify which is which.

A telescope brings Jupiter's yellow-white disc to life, revealing horizontal bands of dark coffee- and caramel-coloured cloud on it as well as round, oval- and lozenge-shaped storm systems, including the famous Great Red Spot, which has been shrinking and fading in colour for quite a while now, neither as great or as red as it once was.

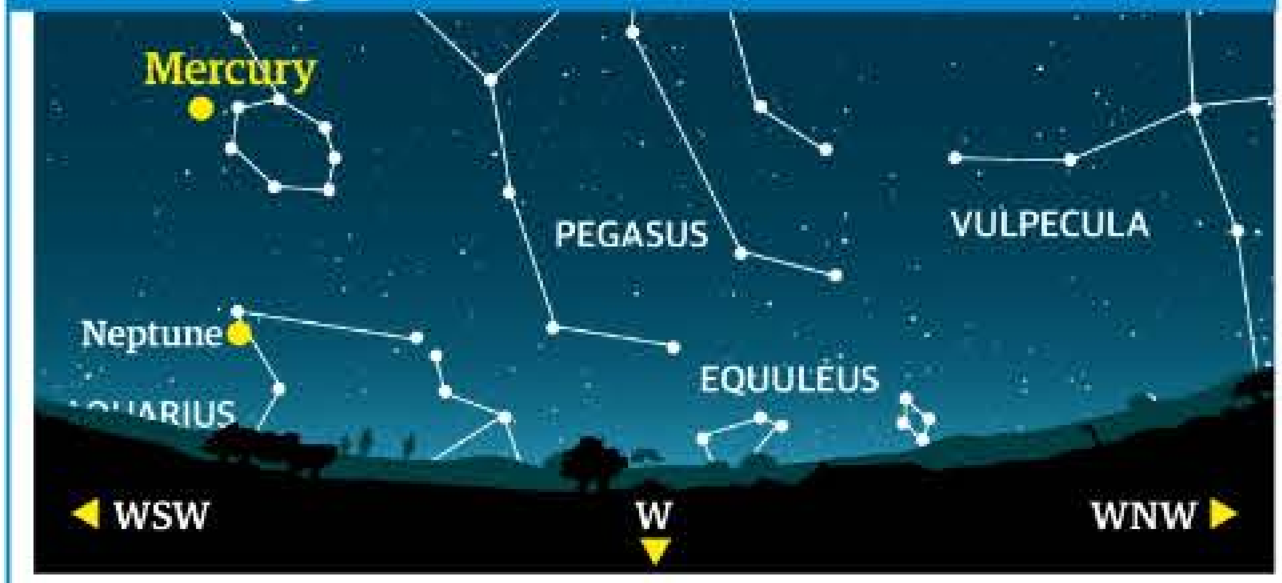
Throughout this month Jupiter is a 'morning star' shining brightly in the east before sunrise. No telescope is needed to see it, and not even a pair of binoculars; it will look like a very bright blue-white star in the sky, brighter than anything else around it. All through the month it will be rising in the southeast around four hours before the Sun and will still be visible in the southern sky as the stars go out one by one with the approach of dawn.

Jupiter has company this month, too. Look to its left and you'll see Saturn shining lower in the east and, further still to the left, lower than but brighter than Saturn, you'll find Venus too. The waning Moon will hopscotch down this line of planets as February ends and March begins: on 27 February the Moon will lie to the lower right of Jupiter, then moving eastwards towards Saturn and Venus.

> "It has been said many times that Jupiter is like a miniature Solar System"

This month's planets

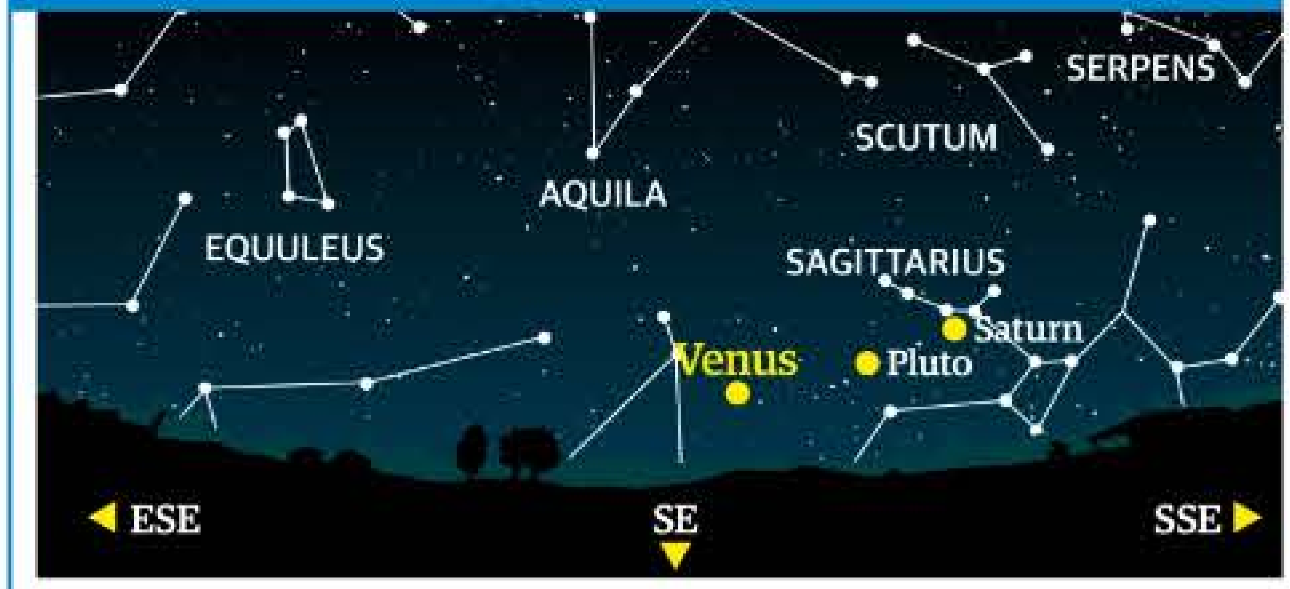
Mercury 17:00 GMT on 04 March



Constellation: Pisces
Magnitude: 0.1
AM/PM: PM

You might just be able to see the closest world to the Sun low in the west after sunset during the first few days of March, but even shining at magnitude 0.1 it might still be too faint to see with the naked eye; you might need to slowly scan around the twilight sky just above the horizon with your binoculars to find it.

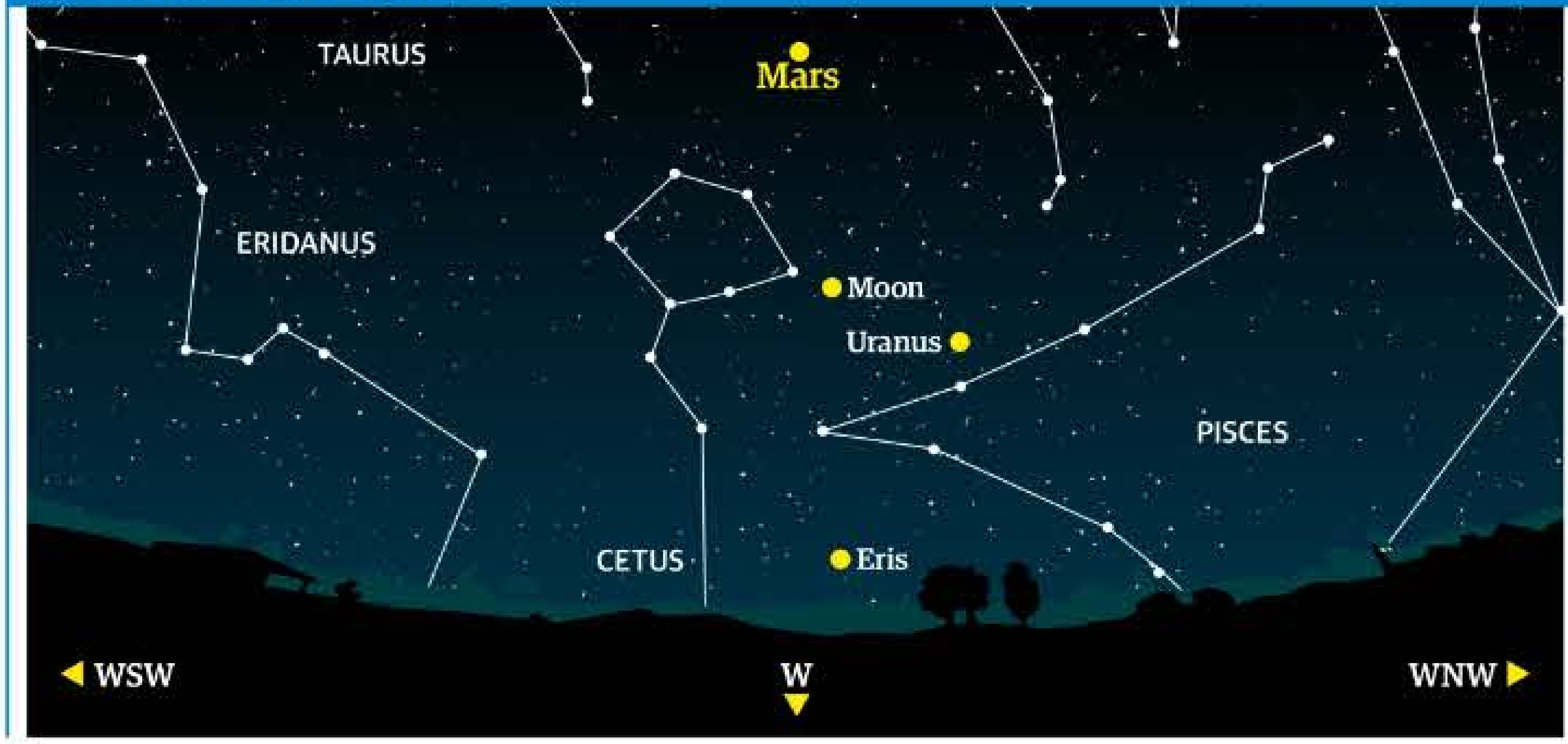
Venus 06:00 GMT on 02 March



Constellation: Sagittarius
Magnitude: -4.1
AM/PM: AM

Venus will be on the eastern end of a chain of three planets, but it will slowly become harder and harder to see as March progresses and it drifts towards the Sun. Look for a beautiful crescent Moon to the right of Venus before sunrise on 2 March, and a thinner crescent Moon to the planet's left the following morning.

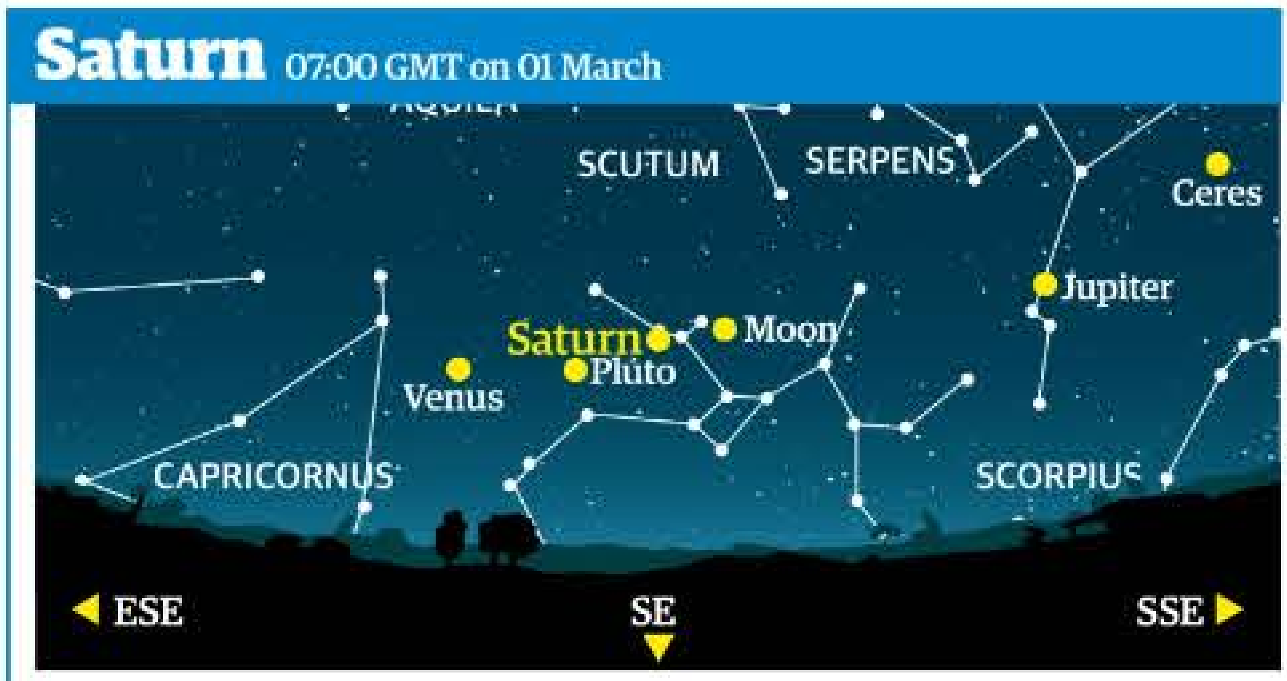
Mars 20:00 GMT on 10 March



Constellation: Aries
Magnitude: 1.1
AM/PM: PM

Mars dominated the sky six months ago, but now it is just a bright, orange star in the constellation of Aries, visible in the western sky from sunset through to late in the evening. Mars' magnitude of 1.1 is still very respectable, but it is only as bright as Pollux, the 18th-brightest star in the sky, so although it is easily visible to the naked eye it is hardly striking. Look for a young crescent Moon passing Mars between 10 and 12 March. Have your binoculars ready at the end of March for when Mars will have moved into Taurus and will lie close to the Pleiades star cluster.

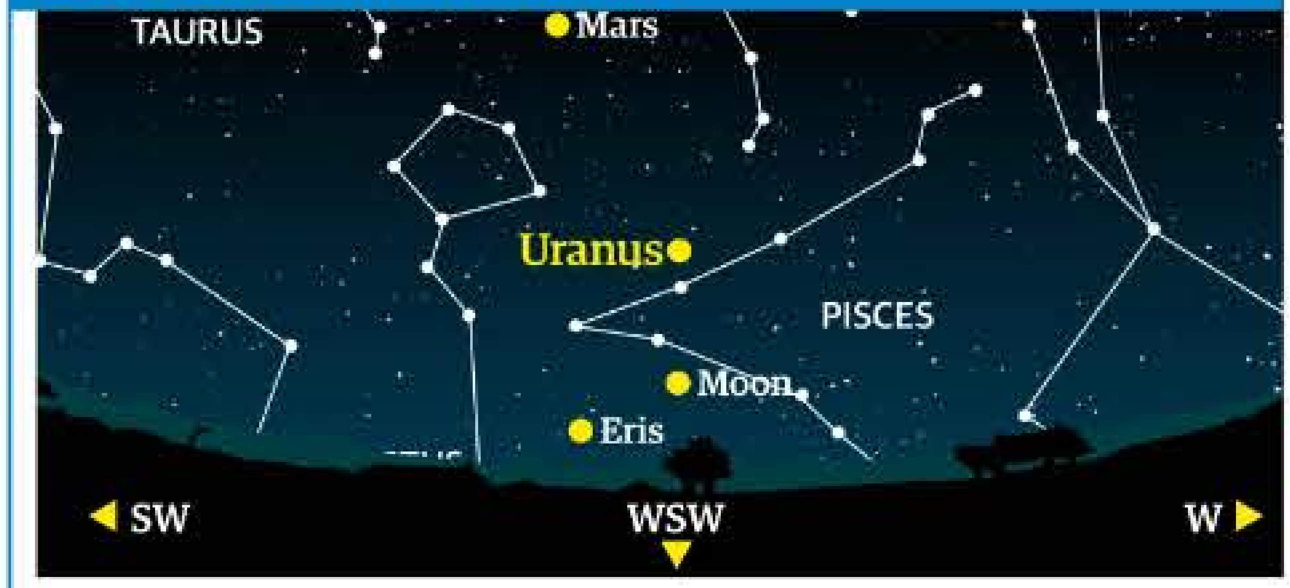
Saturn 07:00 GMT on 01 March



Constellation: Sagittarius
Magnitude: 0.6
AM/PM: AM

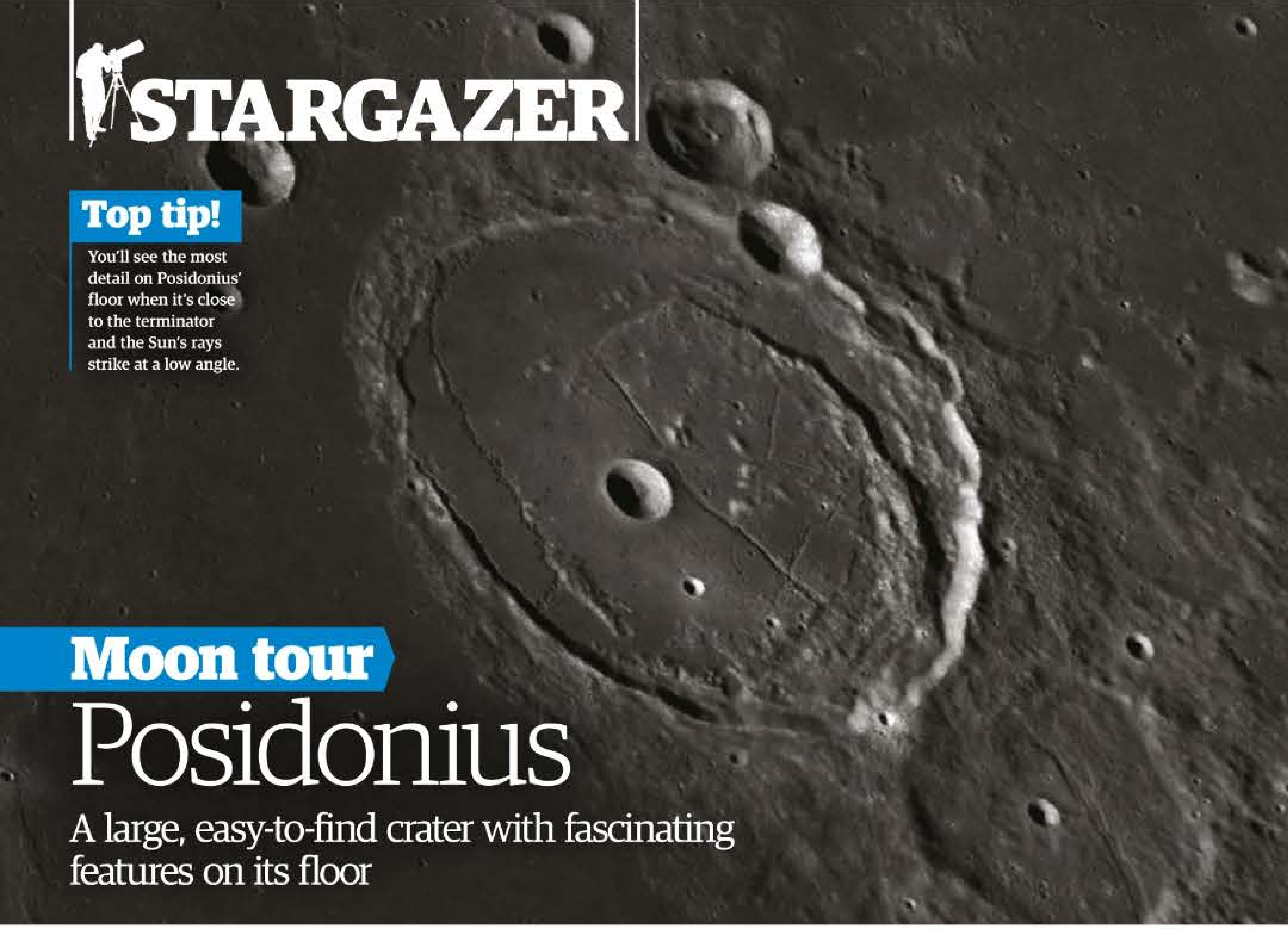
Saturn remains visible in the morning sky, but the best of its display is behind it for now. You'll see it shining low in the southeast in the early hours of the morning. Look out for a waning crescent Moon to the right of Saturn before dawn on 1 March, and to the planet's lower left the following morning.

Uranus 19:00 GMT on 09 March



Constellation: Aries
Magnitude: 5.9
AM/PM: PM

The good news is that, shining at magnitude 5.9, Uranus is technically visible to the naked eye, as the eye's limiting magnitude is 6. This month Uranus is visible in the evening sky after sunset, high in the west, quite close to much brighter Mars. The young crescent Moon will pass it between 9 and 11 March.



Top tip!

You'll see the most detail on Posidonius' floor when it's close to the terminator and the Sun's rays strike at a low angle.

Moon tour

Posidonius

A large, easy-to-find crater with fascinating features on its floor

If you look at the Moon through a telescope at medium to high magnification you'll see that most lunar craters have quite boring floors. True, many have mountains in their centres – central peaks caused by lava bouncing back, sploshing up and then setting in place after they were formed. Many others have smaller craters spattered across their floors, as if they had been hit with buckshot from a shotgun. Others still have valleys or channels running across them, or walls displaying multiple ridges, shelves and terraces. This month's tour destination has most of those, so it is well worth a look as February turns into March and spring impatiently taps us on our shoulders as we peer into our eyepieces.

Posidonius can be found on the northeastern 'shore' of the roughly circular Sea of Serenity that famously represents one of the eyes of the man in the Moon. Posidonius is yet another of those craters that would be much more prominent – and therefore much better known – if it had been formed nearer the centre of the Moon's Earth-facing side; with a diameter of 95 kilometres (59 miles) it is the same width as the glorious 'Monarch of the Moon' Copernicus, and larger than ray-splashed Tycho. Unfortunately Posidonius' position quite close to the Moon's limb means our view of it is foreshortened, and we see it and its features at an oblique angle.

It's a great shame because Posidonius has a lot to offer the observer. It's a low crater with a rim that rises little more than two kilometres (1.24 miles) above the surrounding landscape, and to the northwest that already low rim has been largely covered up by lava flows, making it even less impressive. The crater rim down to the southeast is much more prominent, broken up into ledges and terraces.

Although it looks quite flat at low magnification, look at Posidonius through a telescope at medium to high power and you'll see its floor is strewn with fascinating features. Just to the left of centre on the crater's floor you'll see Posidonius A, a smaller crater just 11 kilometres (6.8 miles) across.

To the left of A you'll see what looks like a very thin crack or channel cut into the floor, running roughly north-south. This is Rimae Posidonius, a sinuous rille etched out of the rock of the crater floor by fast-flowing lava long ago. It winds and meanders across the floor for 130 kilometres (80 miles), starting beneath the northern wall of the crater then following a curving path down to the south, curling around A. Another crack can be seen directly to the right of Posidonius A, but it is much straighter and less interesting.

On the eastern side of Posidonius' floor the surface bulges upwards noticeably, forming a kind of plateau tilted up on its eastern edge. The top of this bulge is cross-hatched with a spider's web of cracks, all much smaller and thinner than Rimae Posidonius but fascinating to hunt for at high magnification.

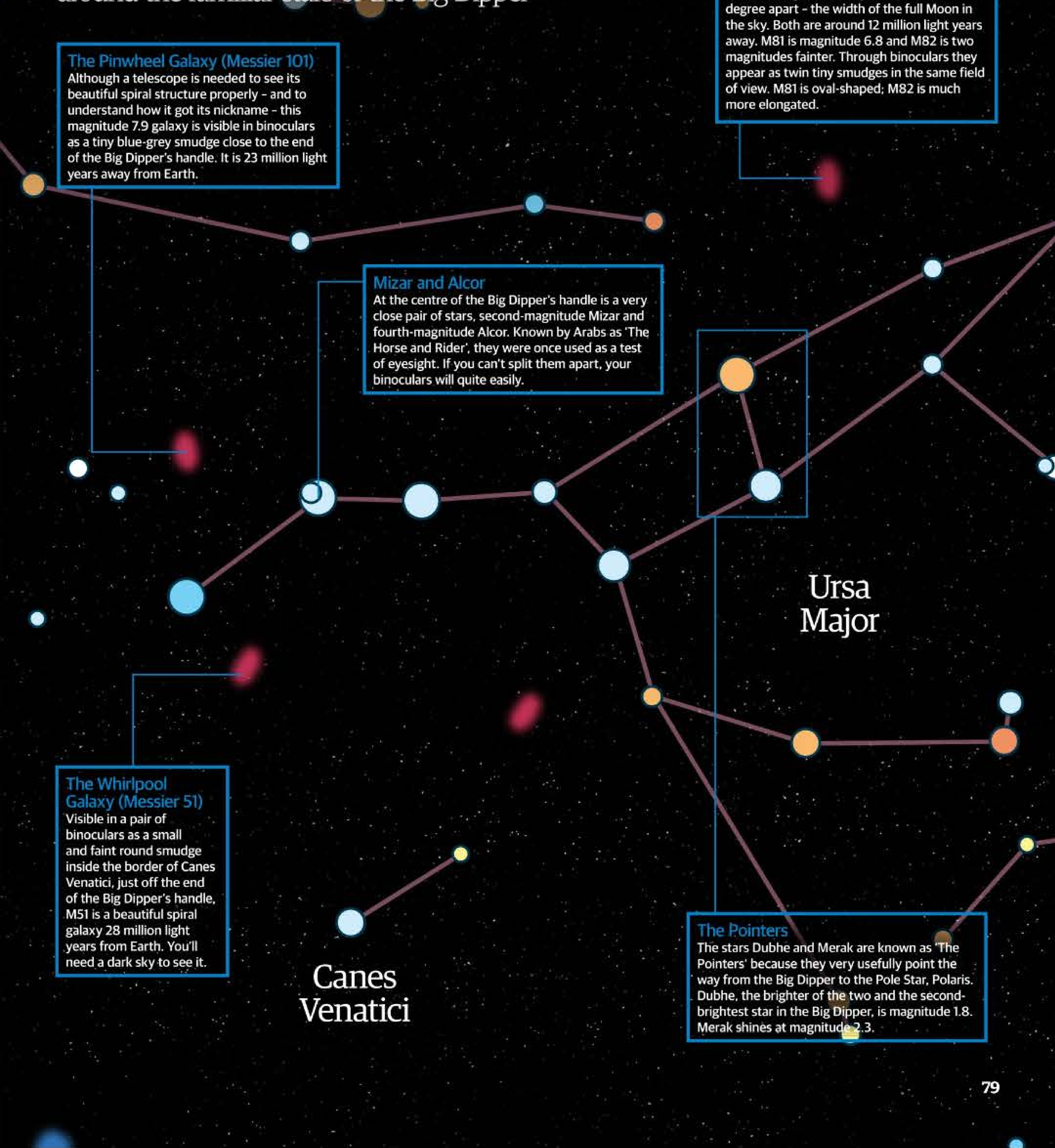
Like every feature on the Moon, Posidonius looks its best when it is close to the terminator, the line between night and day. At that time the Sun's rays come slanting across the crater at a low angle, throwing stark, ink-black shadows behind everything in and around it, and its rilles, cliffs and cracks really stand out dramatically. So, when is the best time to see Posidonius this month?

At the start of March Posidonius can't be seen as it will be deep in lunar night. The crater will become visible on 11 March when the terminator begins to sweep towards it from the east and the Sun rises above the crater. It will be fully lit by the Sun the next evening, the 12th, and will be a stunning sight through a telescope at high magnification. By full Moon on 20 March with the Sun directly above it, Posidonius will look like a pale grey-white ring with a darker centre, but it will begin to look interesting again on the 24th and 25th when the terminator sweeps back over it, throwing its internal features into stark relief again. The crater will be lost from our view on 26 March, and won't return to view until mid-April.

© NASA

Naked eye & binocular targets

March is a great time to explore the wonders to be found around the familiar stars of the Big Dipper



The Pinwheel Galaxy (Messier 101)
Although a telescope is needed to see its beautiful spiral structure properly – and to understand how it got its nickname – this magnitude 7.9 galaxy is visible in binoculars as a tiny blue-grey smudge close to the end of the Big Dipper's handle. It is 23 million light years away from Earth.

M81 and M82
These faint galaxies are just over half a degree apart – the width of the full Moon in the sky. Both are around 12 million light years away. M81 is magnitude 6.8 and M82 is two magnitudes fainter. Through binoculars they appear as twin tiny smudges in the same field of view. M81 is oval-shaped; M82 is much more elongated.

Mizar and Alcor
At the centre of the Big Dipper's handle is a very close pair of stars, second-magnitude Mizar and fourth-magnitude Alcor. Known by Arabs as 'The Horse and Rider', they were once used as a test of eyesight. If you can't split them apart, your binoculars will quite easily.

The Whirlpool Galaxy (Messier 51)
Visible in a pair of binoculars as a small and faint round smudge inside the border of Canes Venatici, just off the end of the Big Dipper's handle, M51 is a beautiful spiral galaxy 28 million light years from Earth. You'll need a dark sky to see it.

The Pointers
The stars Dubhe and Merak are known as 'The Pointers' because they very usefully point the way from the Big Dipper to the Pole Star, Polaris. Dubhe, the brighter of the two and the second-brightest star in the Big Dipper, is magnitude 1.8. Merak shines at magnitude 2.3.

GET READY FOR A SPRING GALAXY TOUR

Take a galactic excursion this month - and into the next - with **All About Space**

There was a time when we thought our Milky Way galaxy was all there is. When, in the 18th century, astronomers like Charles Messier began spotting faint, fuzzy patches of light between the stars, it was thought they must be clouds within our own galaxy. The alternative didn't bear thinking about, that they were faint because they were incredibly far away, much further away than the astronomers of the day could reconcile with their idea of the scale of the universe. This belief was widely held right up until the early 20th century. Eventually, Edwin Hubble was able to show that these foggy smudges were indeed far away, many millions of light years from us, in fact.

Fast-forward to the modern day and observing equipment has never been so cheap and accessible. This has brought these galaxies into the realm of the beginner, meaning you too can marvel at some of the greatest far-off spectacles for yourself. What's more, spring is the best time to begin, as the sky is littered with these cities of stars.

This time of year is particularly favourable because Earth is positioned around the Sun such that at night, we are looking towards many distant galaxy clusters. Draw a triangle between the bright stars Spica (in Virgo), Arcturus (in Boötes) and Regulus (in Leo) and many of the galaxies to look to fall within that space. A few others sit slightly higher around the famous stars of The Big Dipper. Here we've set out a tour of 25 galaxies for you to find, starting near The Big Dipper and ending up inside that triangle in the constellation of Virgo.

First things first, you're never going to get as good a view as professional telescopes like Hubble. The distances of these galaxies mean that they're very faint, and it's often hard to pick out detail unless you have more advanced imaging equipment. Nonetheless, many of these galaxies can be located using just a pair of binoculars. In some cases you'll need a small telescope. The bigger the aperture and the wider the telescope mirror the better. Think of your telescope as a light bucket. The more light you can collect in your bucket, the more distant galaxies you can pick up.

You can employ some useful tips to boost your chance of seeing galaxies. The first trick is called averted vision. Don't look directly at the galaxy, but slightly off to the side. This lets the light into the parts of your eye that are more sensitive to dim light. Another useful tip is to try tapping the tube of your telescope slightly so that it vibrates just a little. This will cause the galaxy to wobble in the field of view, often making it easier to see.

You should also be aware that galaxies aren't always spirals like our Milky Way - and even then some spirals we see edge on, so they aren't as bright or as detailed.

What am I looking at?

Face-on spiral

This is the type of galaxy most people want to see. A city of stars with sweeping dust lanes – angled directly towards us – primed and ready for viewing. You can get 'grand design' spirals with a full set of spiral arms. If the spiral arms and dust lanes appear patchy, however, then they are referred to as flocculent.

Edge-on spiral

These galaxies can be forgiven for appearing bashful. From our fixed vantage point on Earth we see them side on. This means that instead of seeing the spiral arms we are often looking straight into the dust, and they appear as thin, flat discs. It's like looking at the rim of a coin rather than the head or tail.

Intermediate spiral

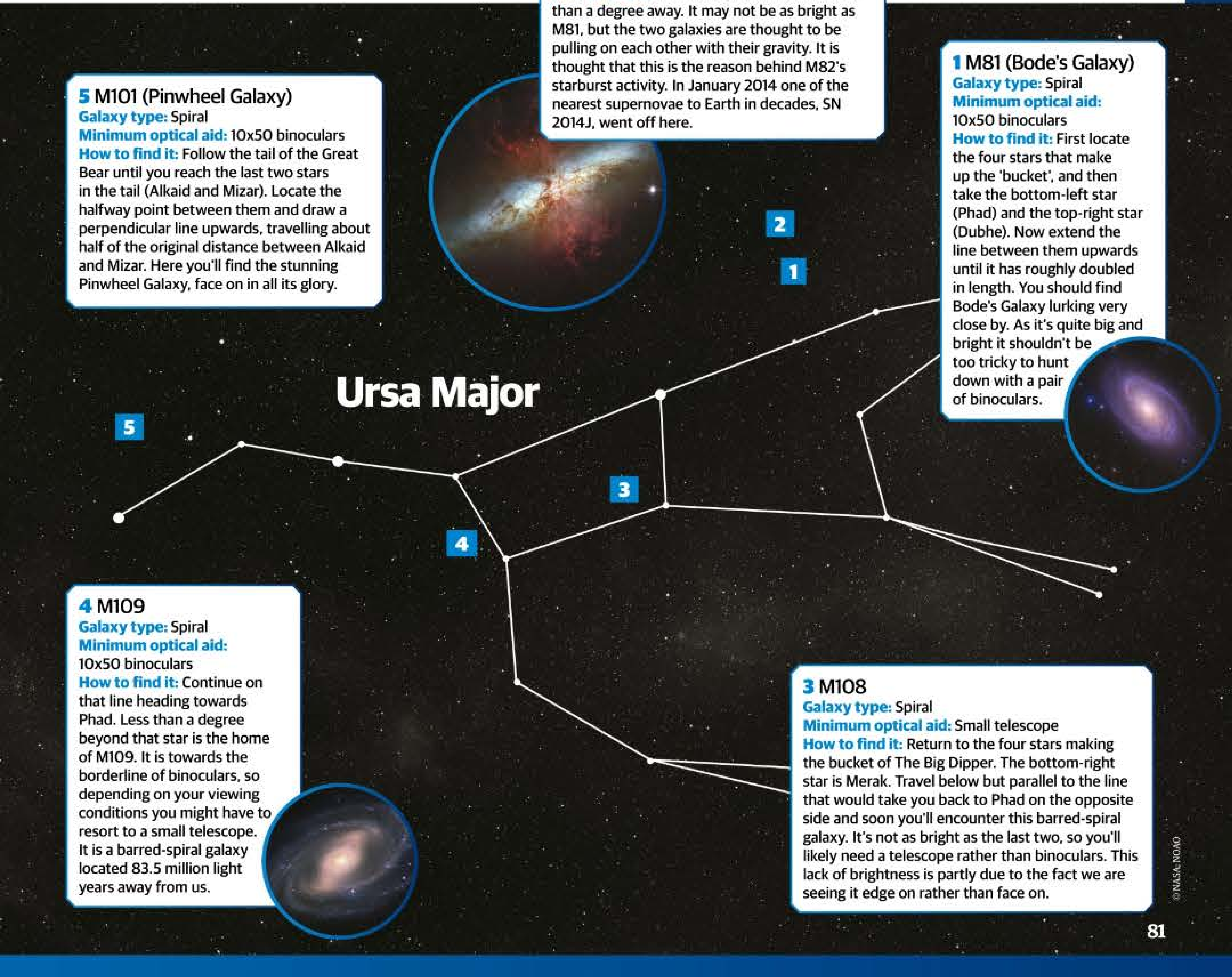
These spirals are betwixt and between face-on and edge-on spiral galaxies. We can see more of the spiral arms than we can with the latter, but not as much as we can with the former.

Elliptical

Not all galaxies are spirals. Elliptical galaxies are often devoid of any features, instead appearing as bright, rugby-ball-shaped blobs. Unlike spirals, which rotate reasonably quickly, ellipticals spin slowly.

Lenticular

While they are flat like a spiral, a lot of their star formation has ceased – they no longer sport distinctive spiral arms. If you're looking at a lenticular galaxy face on it can be easy to mistake it for an elliptical galaxy. Professional astronomers are able to look at the rate the galaxy is rotating to try and find the difference.



1 M81 (Bode's Galaxy)

Galaxy type: Spiral

Minimum optical aid: 10x50 binoculars

How to find it: First locate the four stars that make up the 'bucket', and then take the bottom-left star (Phad) and the top-right star (Dubhe). Now extend the line between them upwards until it has roughly doubled in length. You should find Bode's Galaxy lurking very close by. As it's quite big and bright it shouldn't be too tricky to hunt down with a pair of binoculars.

2 M82 (Cigar Galaxy)

Galaxy type: Starburst galaxy

Minimum optical aid: 10x50 binoculars

How to find it: M82 is very close to M81 – less than a degree away. It may not be as bright as M81, but the two galaxies are thought to be pulling on each other with their gravity. It is thought that this is the reason behind M82's starburst activity. In January 2014 one of the nearest supernovae to Earth in decades, SN 2014J, went off here.

3 M108

Galaxy type: Spiral

Minimum optical aid: Small telescope

How to find it: Return to the four stars making the bucket of The Big Dipper. The bottom-right star is Merak. Travel below but parallel to the line that would take you back to Phad on the opposite side and soon you'll encounter this barred-spiral galaxy. It's not as bright as the last two, so you'll likely need a telescope rather than binoculars. This lack of brightness is partly due to the fact we are seeing it edge on rather than face on.

4 M109

Galaxy type: Spiral

Minimum optical aid: 10x50 binoculars

How to find it: Continue on that line heading towards Phad. Less than a degree beyond that star is the home of M109. It is towards the borderline of binoculars, so depending on your viewing conditions you might have to resort to a small telescope. It is a barred-spiral galaxy located 83.5 million light years away from us.

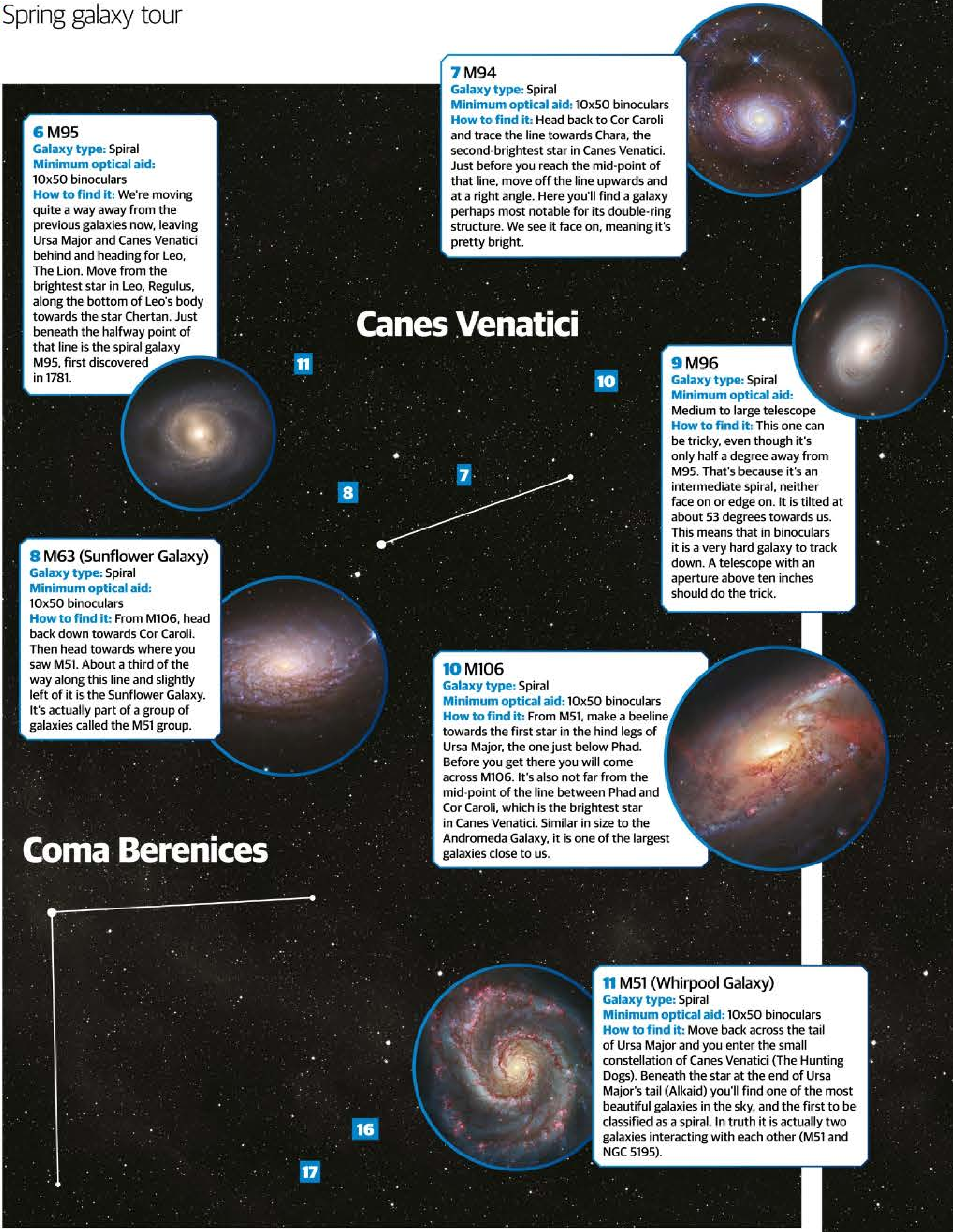
5 M101 (Pinwheel Galaxy)

Galaxy type: Spiral

Minimum optical aid: 10x50 binoculars

How to find it: Follow the tail of the Great Bear until you reach the last two stars in the tail (Alkaid and Mizar). Locate the halfway point between them and draw a perpendicular line upwards, travelling about half of the original distance between Alkaid and Mizar. Here you'll find the stunning Pinwheel Galaxy, face on in all its glory.

© NASA; NOAO



6 M95

Galaxy type: Spiral
Minimum optical aid: 10x50 binoculars
How to find it: We're moving quite a way away from the previous galaxies now, leaving Ursa Major and Canes Venatici behind and heading for Leo, The Lion. Move from the brightest star in Leo, Regulus, along the bottom of Leo's body towards the star Chertan. Just beneath the halfway point of that line is the spiral galaxy M95, first discovered in 1781.

7 M94

Galaxy type: Spiral
Minimum optical aid: 10x50 binoculars
How to find it: Head back to Cor Caroli and trace the line towards Chara, the second-brightest star in Canes Venatici. Just before you reach the mid-point of that line, move off the line upwards and at a right angle. Here you'll find a galaxy perhaps most notable for its double-ring structure. We see it face on, meaning it's pretty bright.

8 M63 (Sunflower Galaxy)

Galaxy type: Spiral
Minimum optical aid: 10x50 binoculars
How to find it: From M106, head back down towards Cor Caroli. Then head towards where you saw M51. About a third of the way along this line and slightly left of it is the Sunflower Galaxy. It's actually part of a group of galaxies called the M51 group.

9 M96

Galaxy type: Spiral
Minimum optical aid: Medium to large telescope
How to find it: This one can be tricky, even though it's only half a degree away from M95. That's because it's an intermediate spiral, neither face on or edge on. It is tilted at about 53 degrees towards us. This means that in binoculars it is a very hard galaxy to track down. A telescope with an aperture above ten inches should do the trick.

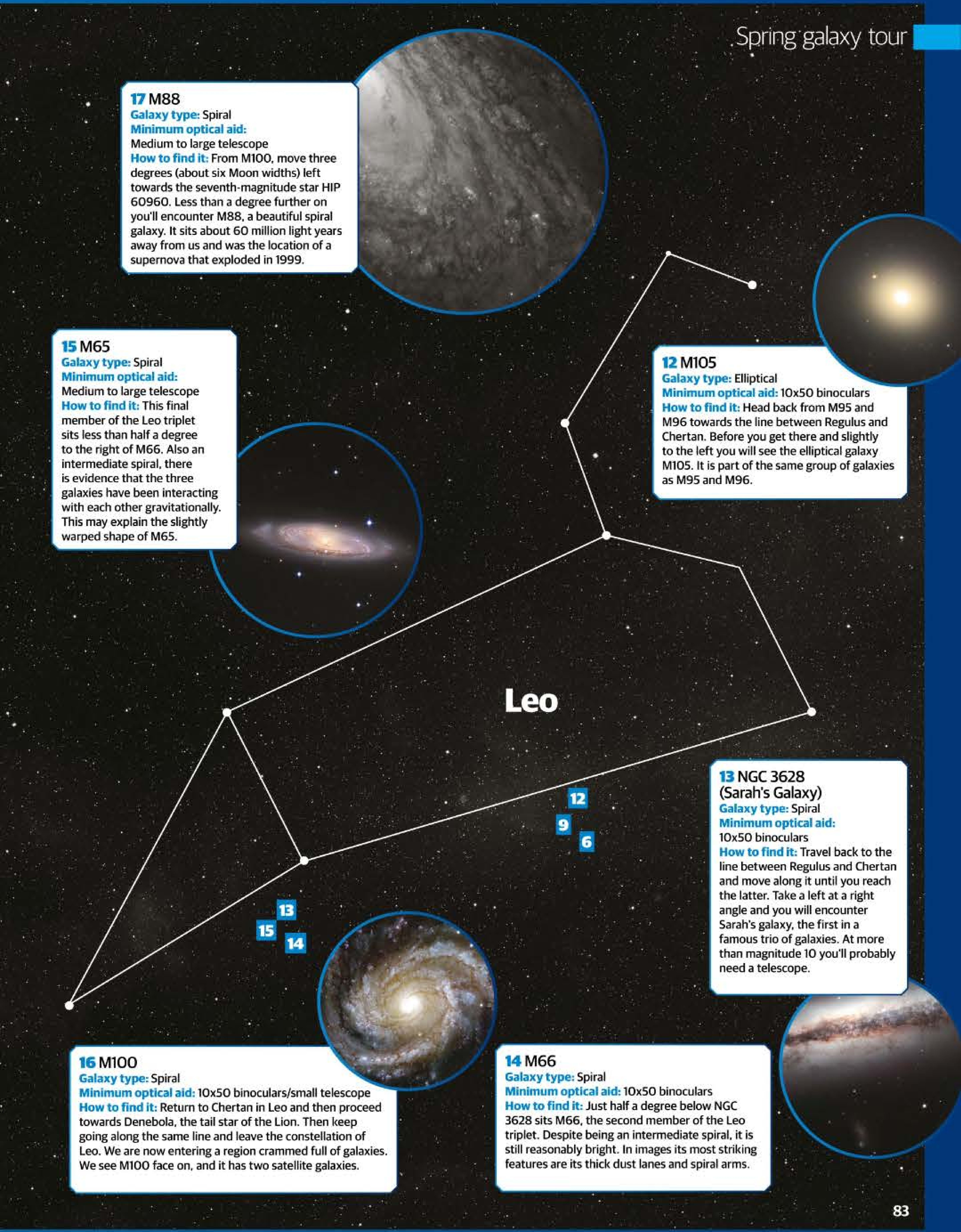
10 M106

Galaxy type: Spiral
Minimum optical aid: 10x50 binoculars
How to find it: From M51, make a beeline towards the first star in the hind legs of Ursa Major, the one just below Phad. Before you get there you will come across M106. It's also not far from the mid-point of the line between Phad and Cor Caroli, which is the brightest star in Canes Venatici. Similar in size to the Andromeda Galaxy, it is one of the largest galaxies close to us.

11 M51 (Whirpool Galaxy)

Galaxy type: Spiral
Minimum optical aid: 10x50 binoculars
How to find it: Move back across the tail of Ursa Major and you enter the small constellation of Canes Venatici (The Hunting Dogs). Beneath the star at the end of Ursa Major's tail (Alkaid) you'll find one of the most beautiful galaxies in the sky, and the first to be classified as a spiral. In truth it is actually two galaxies interacting with each other (M51 and NGC 5195).

© NASA; ESO; ESA; Adam Block/Mount Lemmon SkyCenter/University of Arizona PD; Volker Wendel



17 M88

Galaxy type: Spiral
Minimum optical aid: Medium to large telescope
How to find it: From M100, move three degrees (about six Moon widths) left towards the seventh-magnitude star HIP 60960. Less than a degree further on you'll encounter M88, a beautiful spiral galaxy. It sits about 60 million light years away from us and was the location of a supernova that exploded in 1999.

15 M65

Galaxy type: Spiral
Minimum optical aid: Medium to large telescope
How to find it: This final member of the Leo triplet sits less than half a degree to the right of M66. Also an intermediate spiral, there is evidence that the three galaxies have been interacting with each other gravitationally. This may explain the slightly warped shape of M65.

12 M105

Galaxy type: Elliptical
Minimum optical aid: 10x50 binoculars
How to find it: Head back from M95 and M96 towards the line between Regulus and Chertan. Before you get there and slightly to the left you will see the elliptical galaxy M105. It is part of the same group of galaxies as M95 and M96.

13 NGC 3628 (Sarah's Galaxy)

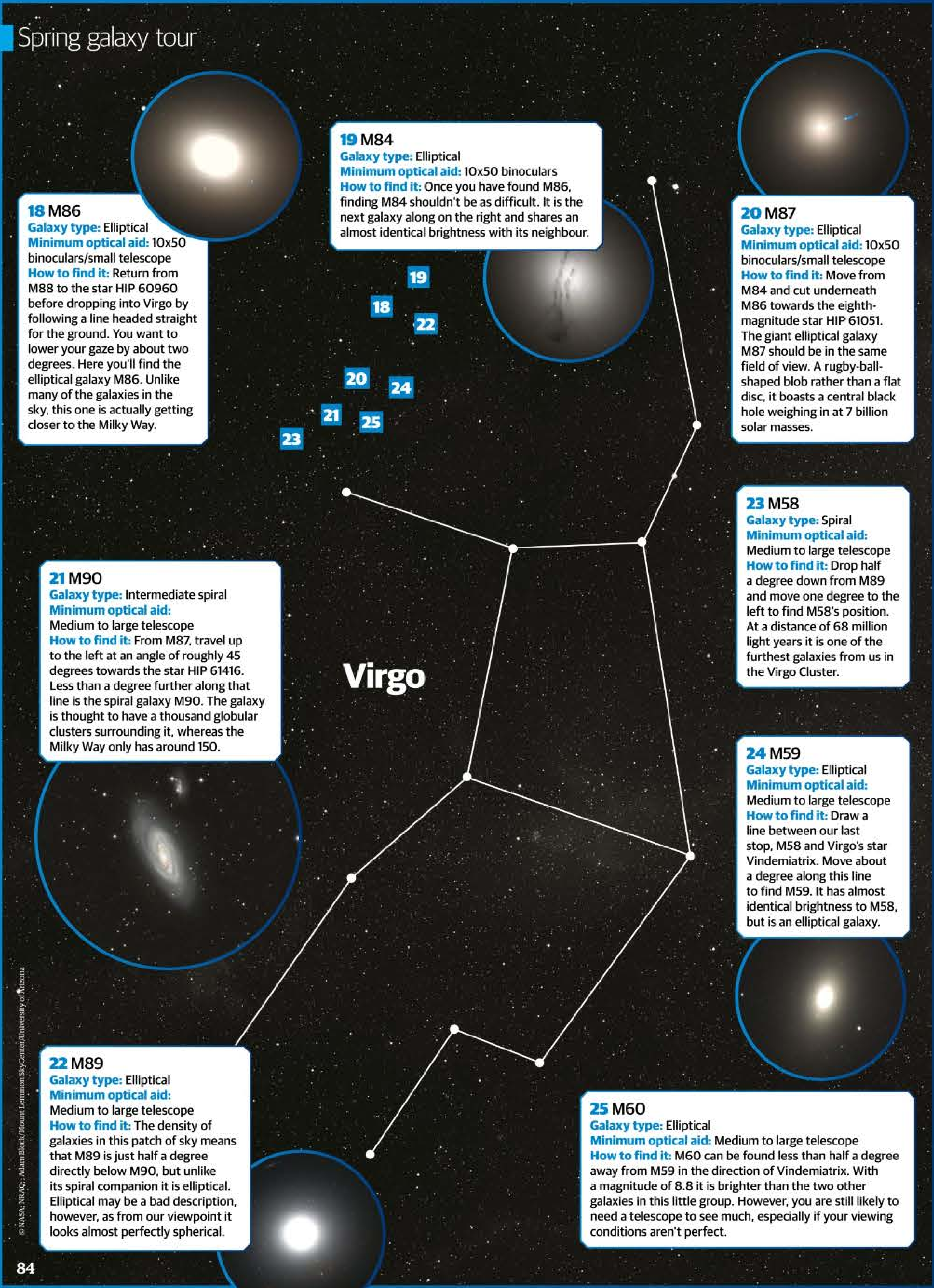
Galaxy type: Spiral
Minimum optical aid: 10x50 binoculars
How to find it: Travel back to the line between Regulus and Chertan and move along it until you reach the latter. Take a left at a right angle and you will encounter Sarah's galaxy, the first in a famous trio of galaxies. At more than magnitude 10 you'll probably need a telescope.

16 M100

Galaxy type: Spiral
Minimum optical aid: 10x50 binoculars/small telescope
How to find it: Return to Chertan in Leo and then proceed towards Denebola, the tail star of the Lion. Then keep going along the same line and leave the constellation of Leo. We are now entering a region crammed full of galaxies. We see M100 face on, and it has two satellite galaxies.

14 M66

Galaxy type: Spiral
Minimum optical aid: 10x50 binoculars
How to find it: Just half a degree below NGC 3628 sits M66, the second member of the Leo triplet. Despite being an intermediate spiral, it is still reasonably bright. In images its most striking features are its thick dust lanes and spiral arms.



18 M86

Galaxy type: Elliptical
Minimum optical aid: 10x50 binoculars/small telescope
How to find it: Return from M88 to the star HIP 60960 before dropping into Virgo by following a line headed straight for the ground. You want to lower your gaze by about two degrees. Here you'll find the elliptical galaxy M86. Unlike many of the galaxies in the sky, this one is actually getting closer to the Milky Way.

19 M84

Galaxy type: Elliptical
Minimum optical aid: 10x50 binoculars
How to find it: Once you have found M86, finding M84 shouldn't be as difficult. It is the next galaxy along on the right and shares an almost identical brightness with its neighbour.

20 M87

Galaxy type: Elliptical
Minimum optical aid: 10x50 binoculars/small telescope
How to find it: Move from M84 and cut underneath M86 towards the eighth-magnitude star HIP 61051. The giant elliptical galaxy M87 should be in the same field of view. A rugby-ball-shaped blob rather than a flat disc, it boasts a central black hole weighing in at 7 billion solar masses.

21 M90

Galaxy type: Intermediate spiral
Minimum optical aid: Medium to large telescope
How to find it: From M87, travel up to the left at an angle of roughly 45 degrees towards the star HIP 61416. Less than a degree further along that line is the spiral galaxy M90. The galaxy is thought to have a thousand globular clusters surrounding it, whereas the Milky Way only has around 150.

22 M89

Galaxy type: Elliptical
Minimum optical aid: Medium to large telescope
How to find it: The density of galaxies in this patch of sky means that M89 is just half a degree directly below M90, but unlike its spiral companion it is elliptical. Elliptical may be a bad description, however, as from our viewpoint it looks almost perfectly spherical.

23 M58

Galaxy type: Spiral
Minimum optical aid: Medium to large telescope
How to find it: Drop half a degree down from M89 and move one degree to the left to find M58's position. At a distance of 68 million light years it is one of the furthest galaxies from us in the Virgo Cluster.

24 M59

Galaxy type: Elliptical
Minimum optical aid: Medium to large telescope
How to find it: Draw a line between our last stop, M58 and Virgo's star Vindemiatrix. Move about a degree along this line to find M59. It has almost identical brightness to M58, but is an elliptical galaxy.

25 M60

Galaxy type: Elliptical
Minimum optical aid: Medium to large telescope
How to find it: M60 can be found less than half a degree away from M59 in the direction of Vindemiatrix. With a magnitude of 8.8 it is brighter than the two other galaxies in this little group. However, you are still likely to need a telescope to see much, especially if your viewing conditions aren't perfect.

© NASA; NRAO; Adam Block/Mount Lemmon SkyCenter/University of Arizona

WIN

OREGON OBSERVATION 20X80

Supplied by Opticron, these binoculars provide clear and crisp views of a selection of terrestrial and astronomical targets

The Oregon Observation 20x80 binoculars are the perfect companion for not just viewing the landscape and wildlife on Earth but also getting up close to the variety of planets, galaxies, nebulae and star clusters that populate our night skies.

Fitted with a BAK-4 Porro-prism multi-coated optical system, these exquisite binoculars provide an excellent object magnification, while maintaining crisp and contrasted colours.

These exquisite binoculars also feature fold-down rubber eyecups, a soft carry case with rainguard and a wide nylon strap. Along with its integral tripod adapter socket and comfortable, long eye relief eyepieces, a long night of observing can be had with minimum effort.

To be in with a chance of winning, all you have to do is answer this question:

Observers in Australia, New Zealand and South America will see which planet make an occultation with the Moon on 25 April 2019?

A: Jupiter

B: Saturn

C: Mars

Competition ends on 28 March 2019

Enter via email at **space@spaceanswers.com** or by post to
All About Space competitions, Richmond House,
33 Richmond Hill, Bournemouth, BH2 6EZ

Visit the website for full terms and conditions at **www.spaceanswers.com/competitions**

WORTH £149!

Congratulations to Warren Jacobs, who has won a Meade Polaris 114 reflector telescope!

How to...

Use Stellarium

Here's how to use one of the most popular planetarium programs available to plan your observing nights in advance

You'll need:

- ✓ A PC or laptop
- ✓ Internet connection to download the program

Before the digital revolution - when the only phones we had were tied to our living-room walls by a cable or mounted in a drafty, cobweb-draped box at the end of the street - if amateur astronomers wanted to plan an observing night in advance our options were rather limited. Monthly magazines featured star charts accompanied by notes on which planets and comets would be visible that coming month. We also used planispheres, round star charts made of card or plastic which you turned, like a wheel, to show the stars and constellations we'd be able to see at a certain time on a certain date - but they couldn't tell us where the Moon and planets would be. There were also various annual guides available for us to buy. It was all very low tech.

When computers came along, everything changed. Now we could use software to simulate views of the sky for any time on any date, just by clacking away on a keyboard or clicking a mouse. Today we do the same with mobile device apps, but not so long ago it was a real novelty to use such 'planetarium programs' to help us plan our activities.

At the height of their popularity around a dozen different ones were available, including some very advanced ones you could use to run an observatory with, but through the years one much more simple planetarium program has held its own and held a special place in astronomers' hearts too: Stellarium. And it's a safe bet to guess that most amateur astronomers, veterans or newbies, advanced or beginners, has it on their PC or laptop today and uses it regularly.

> "We could use software to simulate views of the sky for any time on any date"

Tips & tricks

Check your specs

Make sure you download a version of the program which will work on your machine, suitable for its processor speed, memory and graphics card.

Start off at home

Before using Stellarium to wander off and explore the skies of other countries and cultures, use it to view the sky from where you live.

Be patient

Although Stellarium is easier to use than other planetarium programs it still takes time to get used to all its features. Take your time with it!

Keep it real

Keeping the view simple with naked-eye stars will help you learn the sky.

Roam the world

It's fascinating to use Stellarium to virtually view the sky from different sites around the world. You can use it to stand beneath the southern sky without leaving your front room.

Explore other cultures

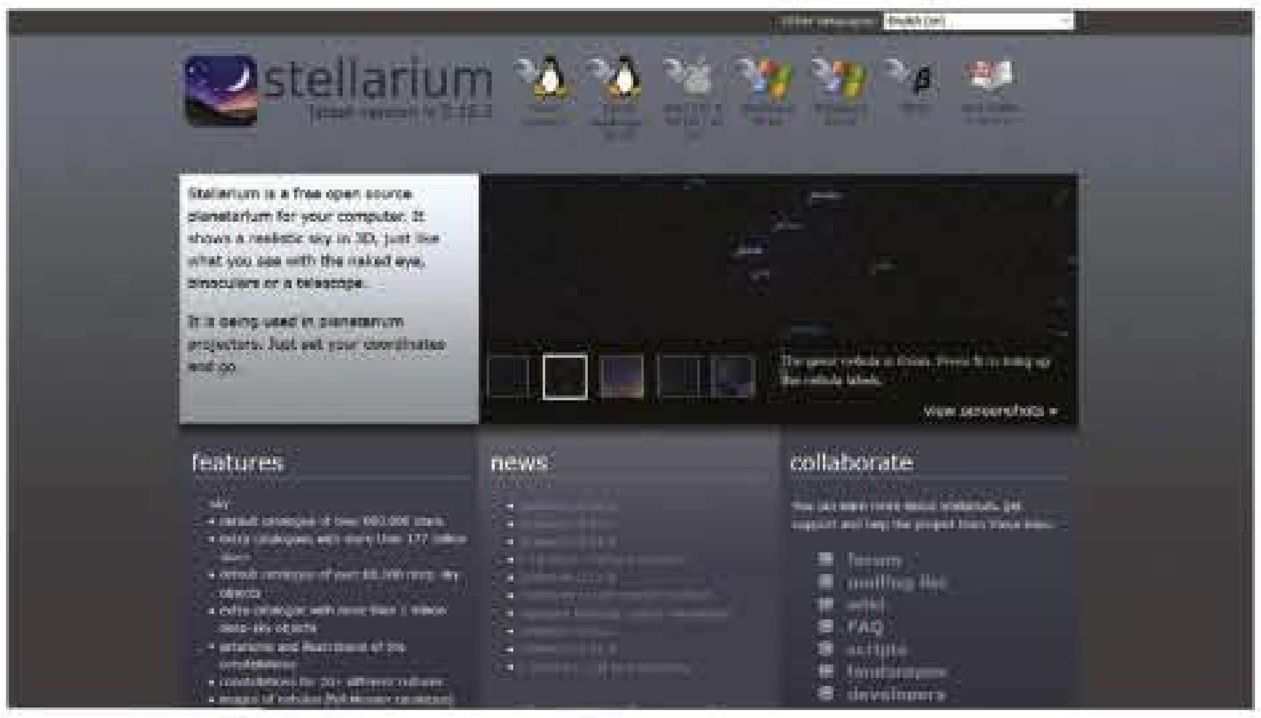
Stellarium will let you see the sky through the eyes of other cultures, showing the constellations created by the ancient Eygptians, Mayans and even the Vikings!

Making the most of your software

Why Stellarium is such a popular program with astronomers

One obvious appeal is it's free, but that's not the main reason. It has lots of features, but isn't cluttered like many other programs or apps – it shows the night sky realistically without too many lines and symbols. Stellarium also lets you import the details of newly discovered Solar System objects without too much fuss, so you can find out when a new comet will be visible from where you live.

Stellarium can be downloaded from: **stellarium.org**

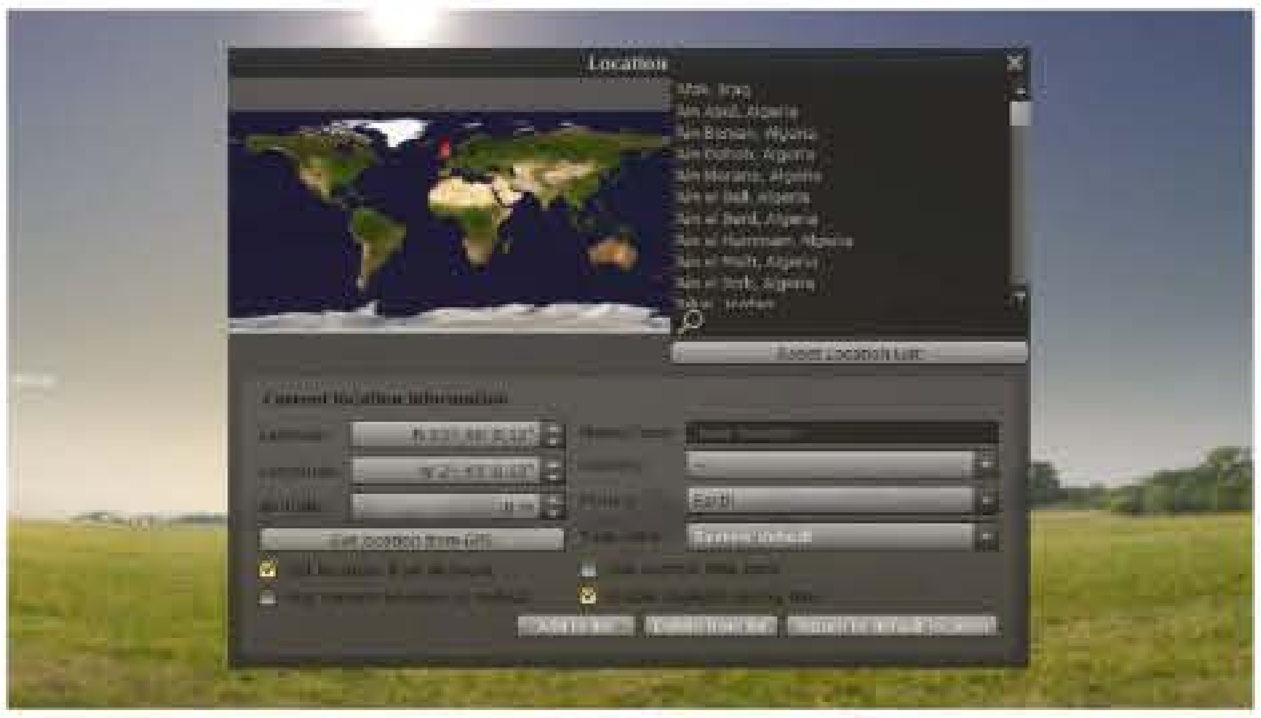


Stellarium is a free open source planetarium for your computer. It shows a realistic sky in 3D, just like what you see with the naked eye, binoculars or a telescope.

It is being used in planetarium projectors. Just set your coordinates and go.

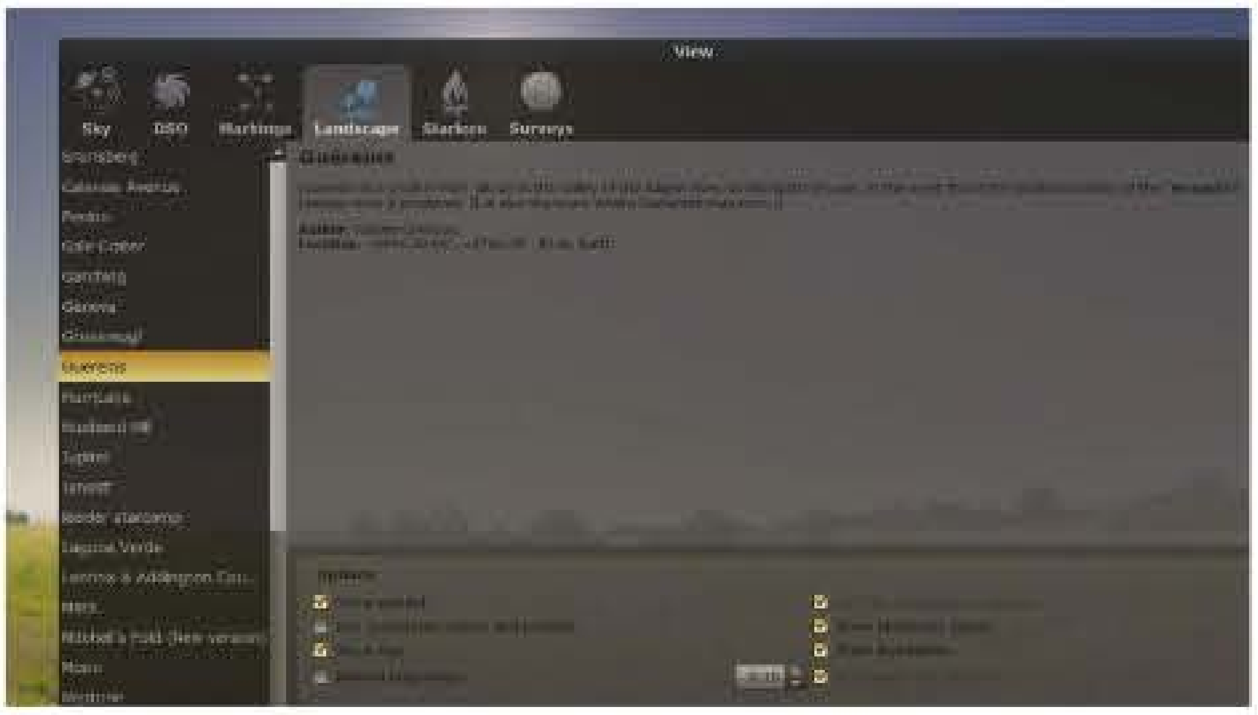
1 Head over to stellarium.org

Download Stellarium from its own dedicated website, making sure to download a version which will run properly on your machine.



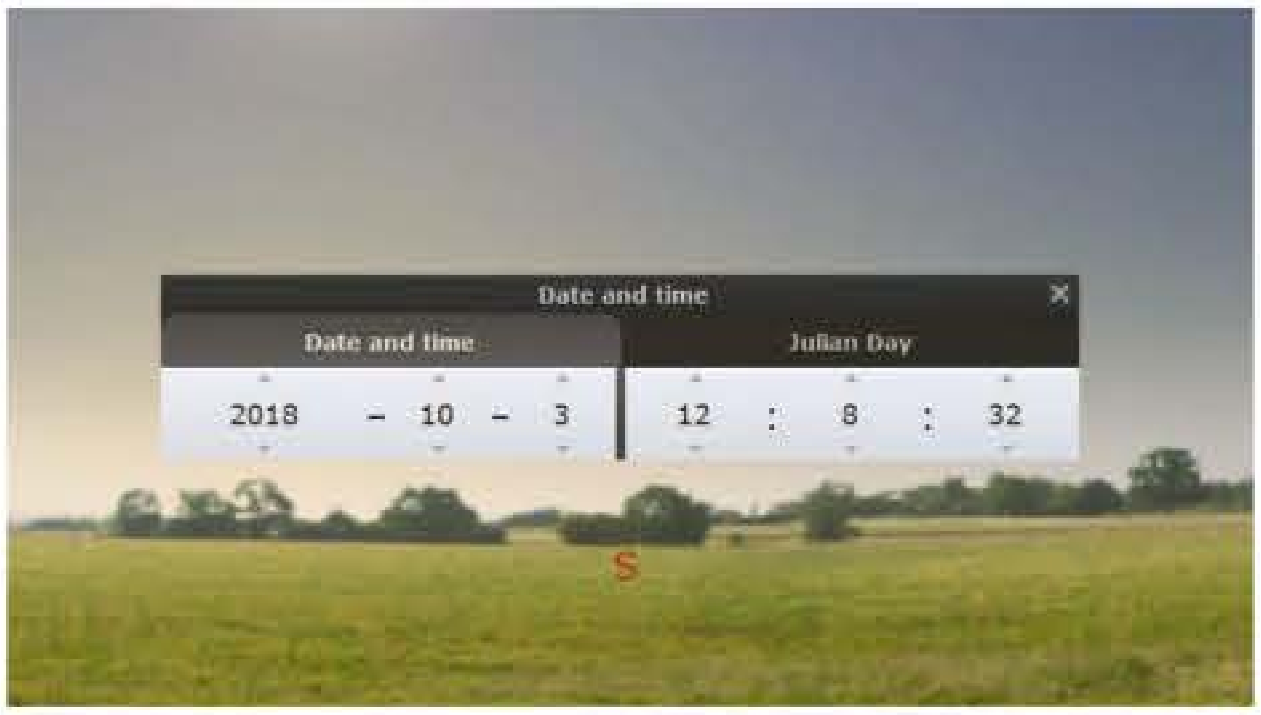
2 Find your location

Select your home location either by finding it on the map or selecting it, or somewhere close to it, from the extensive list of locations.



3 Work out your horizon

Choose a foreground that looks most like your own viewing location. This will give you a realistic view of the sky you see when you observe.

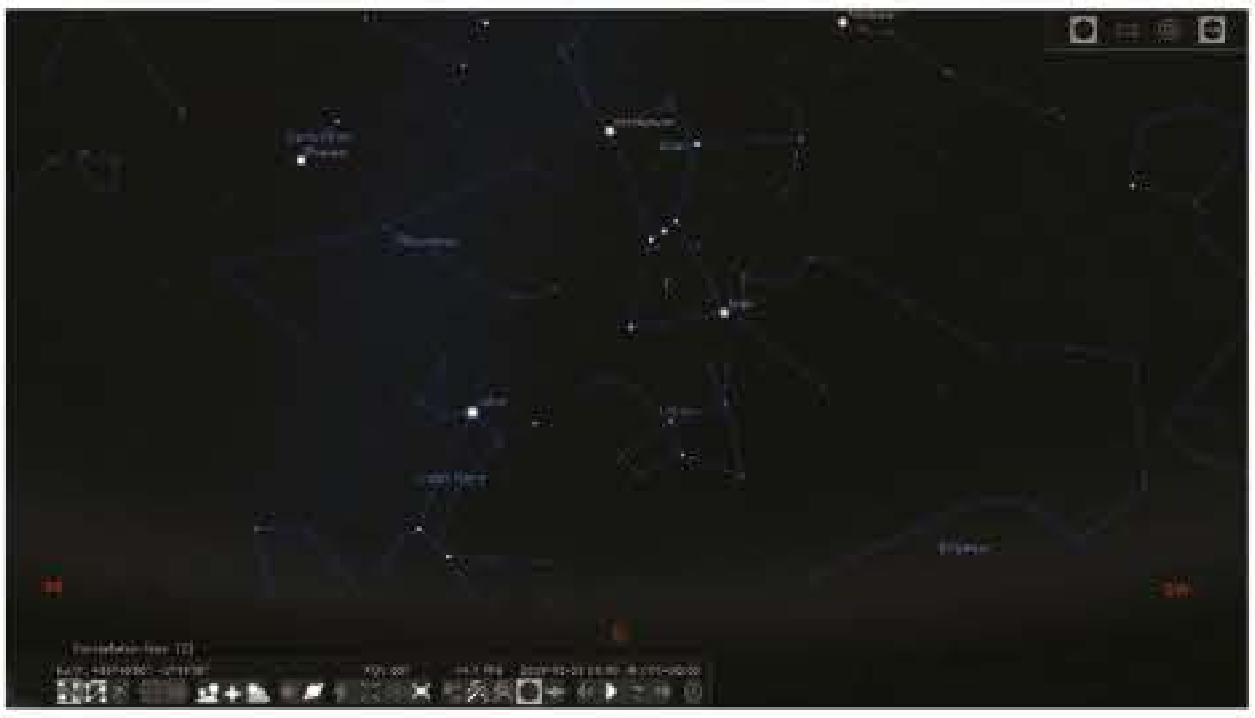


Date and time

Date and time					Julian Day				
2018	-	10	-	3	12	:	8	:	32

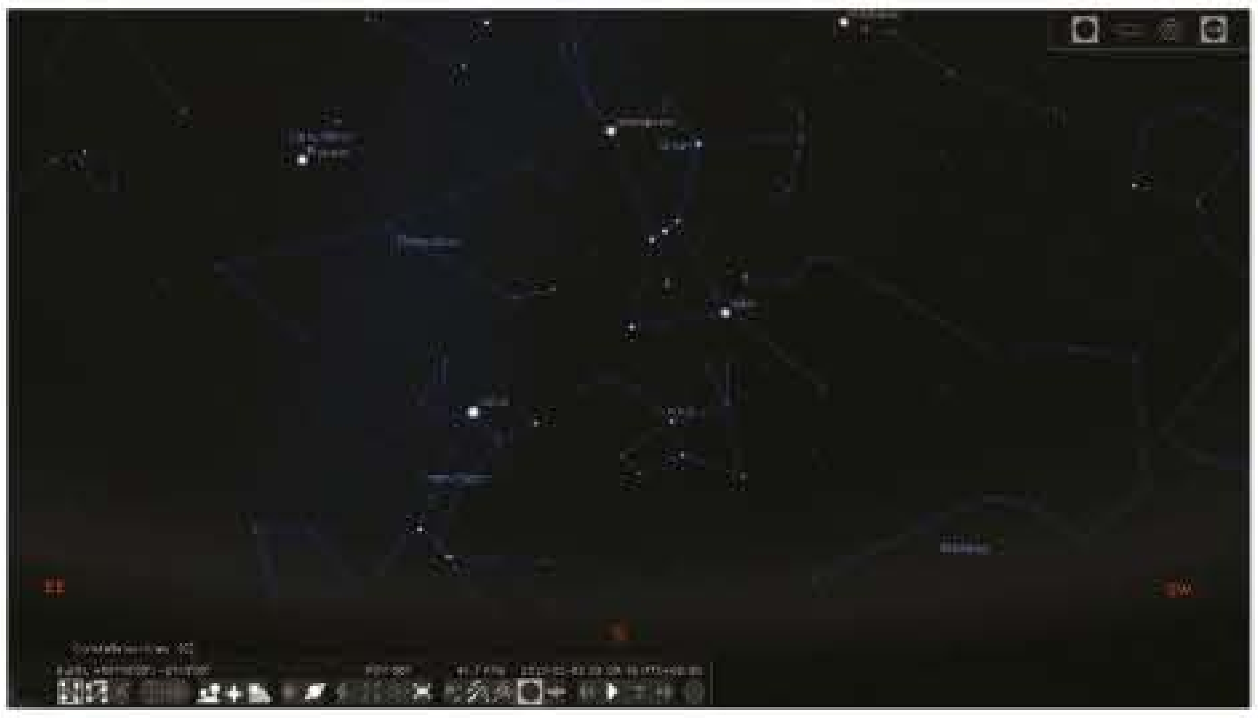
4 Alter the time and date

You can move backwards or forwards in time using the time bar to see how the sky changes over days, weeks, years and even centuries.



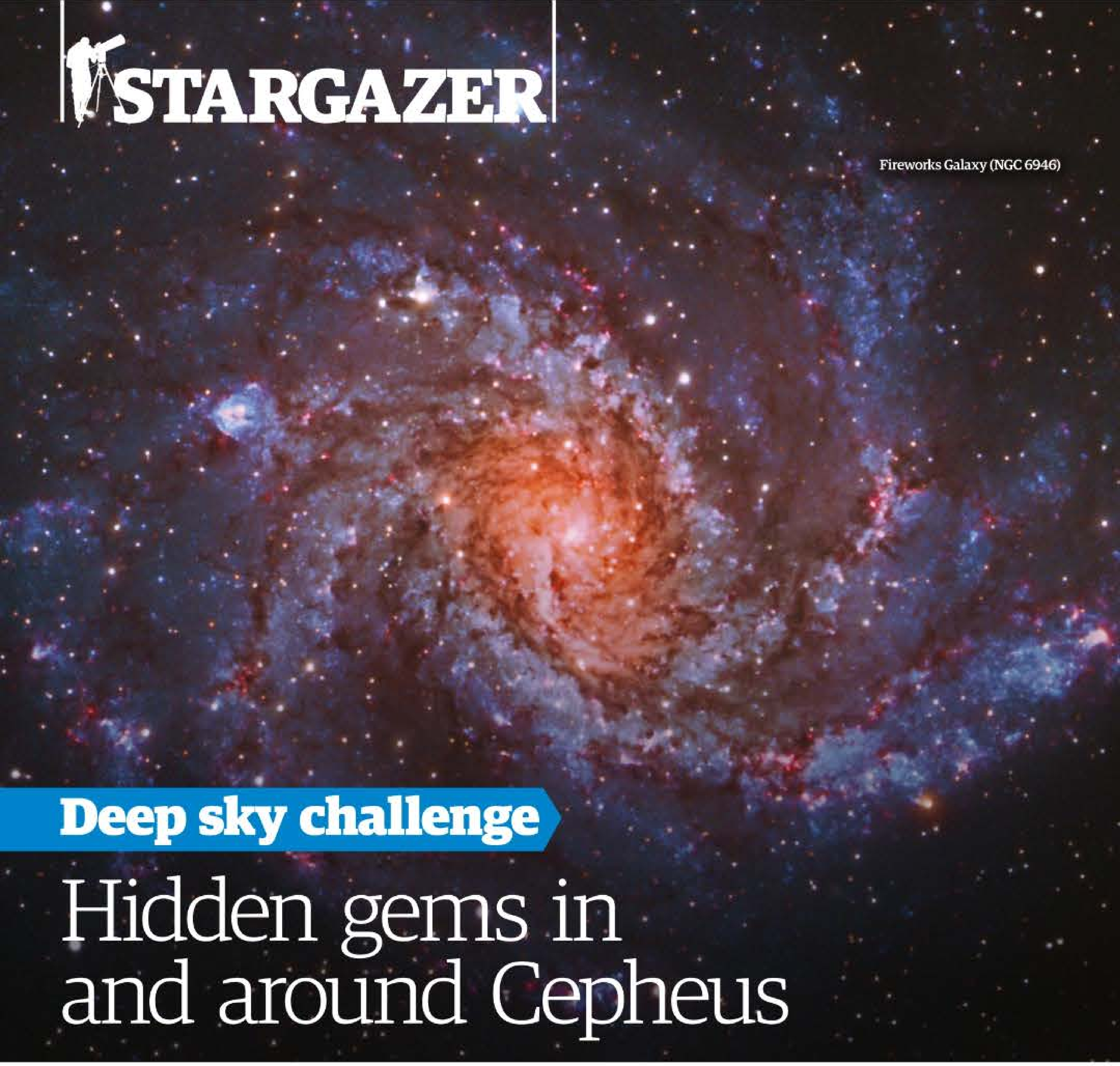
5 Play with the settings

You can turn the names, outlines and artwork of constellations on and off with the tools bar along the bottom of the screen.



6 Check out other ancient skies

Use the Starlore menu to see how the ancient Egyptians, Chinese and Vikings saw the sky and painted it with their own constellations.



Fireworks Galaxy (NGC 6946)

Deep sky challenge

Hidden gems in and around Cepheus

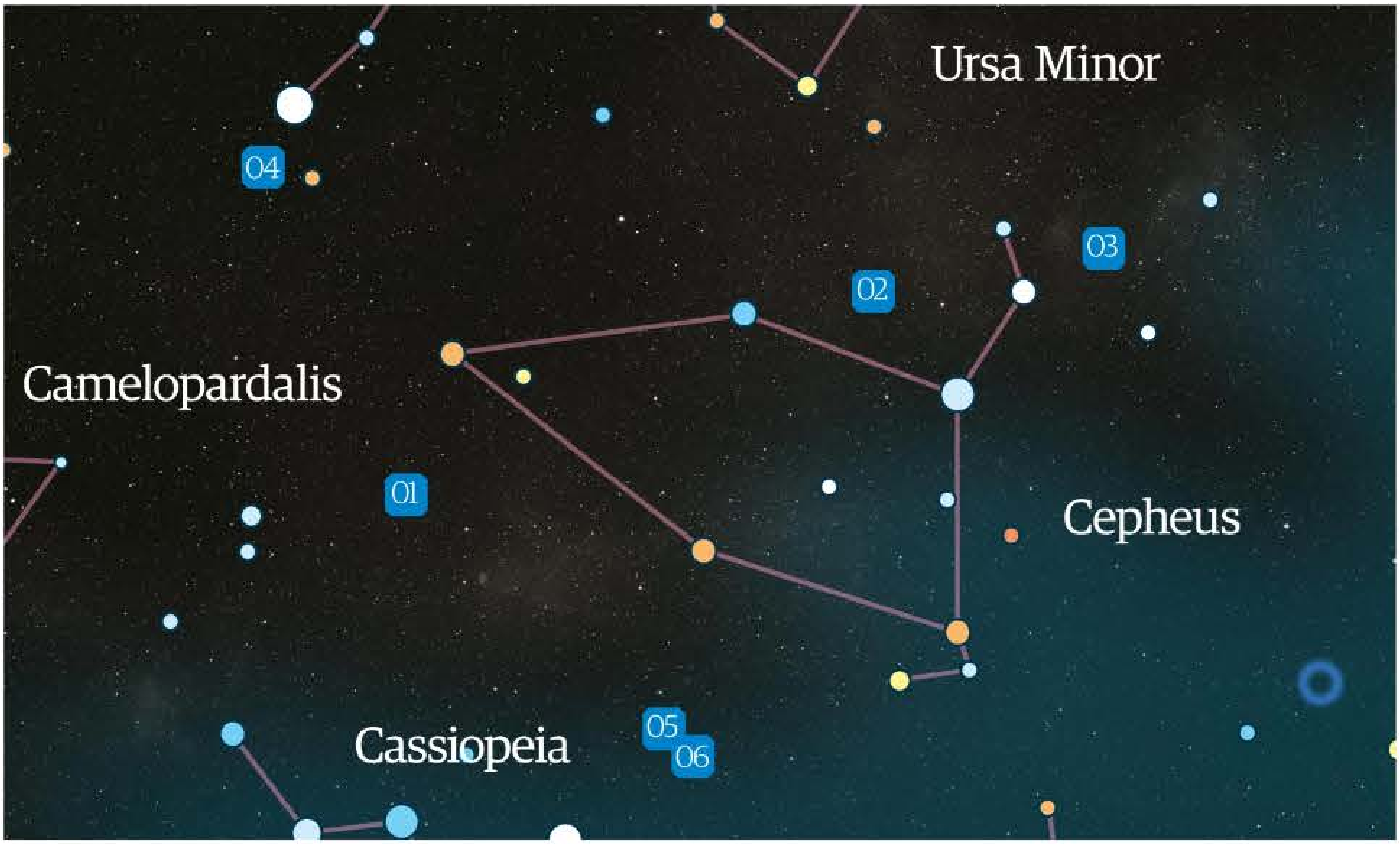
One of the least famous constellations offers keen-eyed observers some fascinating and beautiful sights

It's an unspoken truth that while some constellations are slap-across-the-face gorgeous and blessed with spectacular telescopic treats – Orion, Taurus, I'm looking at you – others are just... boring. With no bright stars they are dull to the naked eye, and they have no big, bright deep-sky objects that cry out to be drooled over through a low-power eyepiece. One such constellation is Cepheus, The King. To the naked eye its faint stars make the shape of a child's crude drawing of a house, and that's it. However, if you swing a medium- or large-aperture telescope towards it you'll be rewarded with views of some genuinely fascinating and attractive objects.

Dim planetary nebula NGC 40 is known as the Bow Tie Nebula, so if you're a *Doctor Who* fan you're legally obliged to track that one down, surely. Spectacular spiral galaxy NGC 6946, known as the Fireworks Galaxy, actually in Cygnus but right on the border with Cepheus, is a popular photographic target for astrophotographers, and seeing it through a large telescope will show you why.

So, this March, as the galaxies of Virgo call out to you from the east and the whirls and swirls of the Orion Nebula whisper from the west, put your hands over your ears, tilt your telescope up and take a tour of Cepheus and the sky around it. You'll be glad you did.

Iris Nebula (NGC 7023)



1 Bow Tie Nebula (NGC 40)
At magnitude 10.6 this dim planetary nebula needs an 8" or larger telescope to show its subtle oval shape. Its bright central star is more obvious.

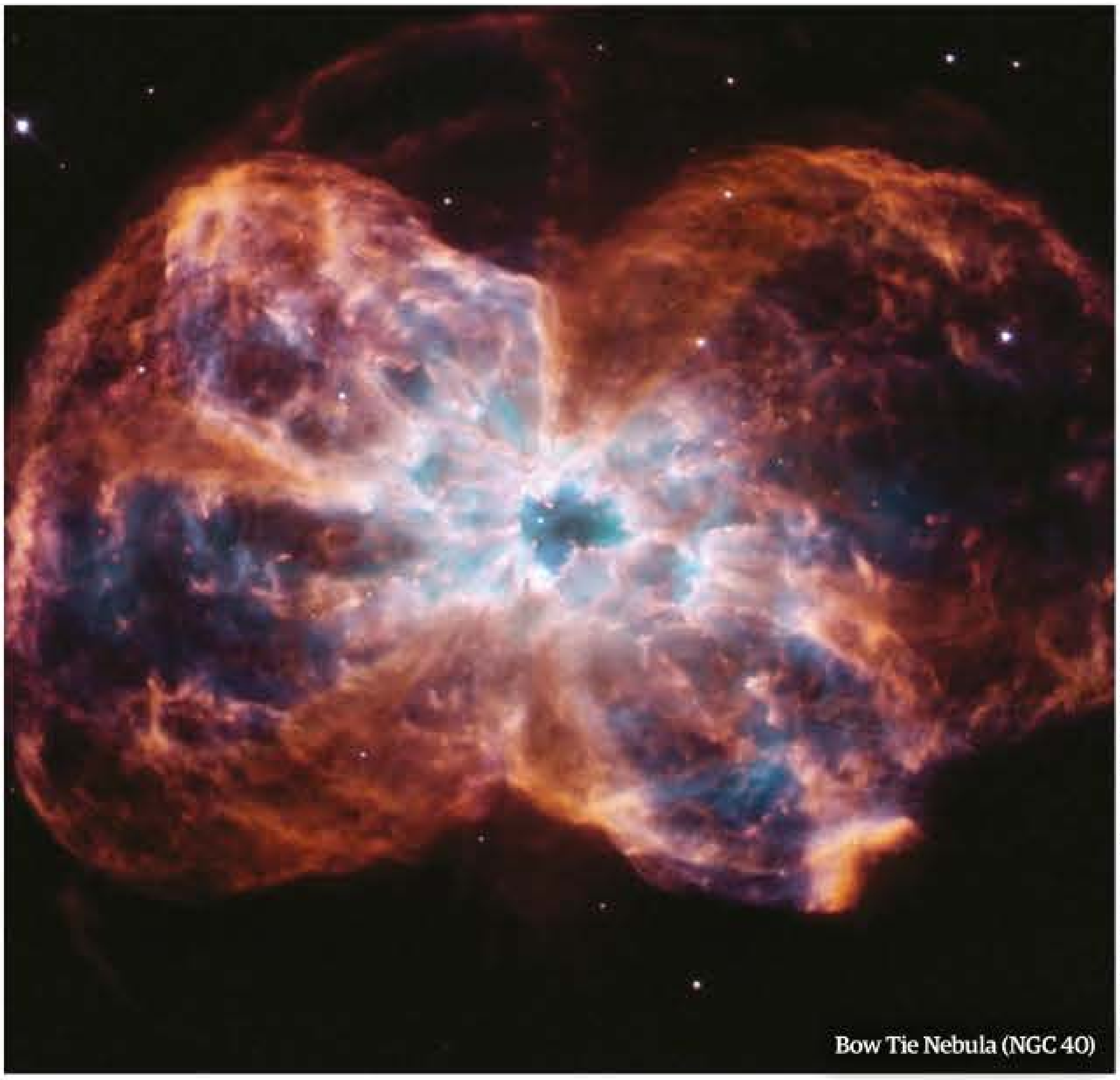
2 Iris Nebula (NGC 7023)
Despite being seventh magnitude, you'll need a large telescope to see this nebula due to its low surface brightness. Averted vision and high magnification will help show its dark dust lanes.

3 Fireworks Galaxy (NGC 6946)
This ninth magnitude spiral galaxy is 10 million light years away. Oriented face on to us, under a dark sky a large telescope will reveal its beautifully curved spiral arms and mottled detail.

4 NGC 188
Very close to Polaris, this open cluster is 9 billion years old, one of the oldest known. It is an 8th magnitude dusting of faint stars best seen through a large telescope.

5 Bubble Nebula (NGC 7635)
You'll only see the ghostly glowing shell of this very faint, 12th-magnitude nebula in Cassiopeia through a large telescope under a very dark sky. At least a 14-inch 'scope will show subtle detail.

6 Messier 52
Just over Cepheus' border in Cassiopeia, this seventh-magnitude open cluster can be seen as a smudge through small telescopes, but larger instruments will resolve it into 200 or so faint stars.



Bow Tie Nebula (NGC 40)

© NASA; ESA; Göran Nilsson & The Liverpool Telescope; Hewholooks

The Northern Hemisphere

Ursa Major, the Great Bear, signals a change in the night sky as it hangs high overhead

As the brilliant winter constellations – which include Orion and Canis Major – start to slip westwards, setting ever earlier, the familiar star patterns of Leo and Virgo begin to climb to centre stage.

And that's not all; Ursa Major (the Great Bear) is plain for all observers to see and contains the seven familiar stars of the Big Dipper. The Great Bear is a treasure trove, offering a selection of double stars, nebulae and galaxies to push your instrument to the limit. And, given we're in March, you should be able to see a faint glowing triangle from the horizon up – zodiacal light, a true delight for those observing from dark locations.

Using the sky chart

This chart is for use at 10pm (GMT) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

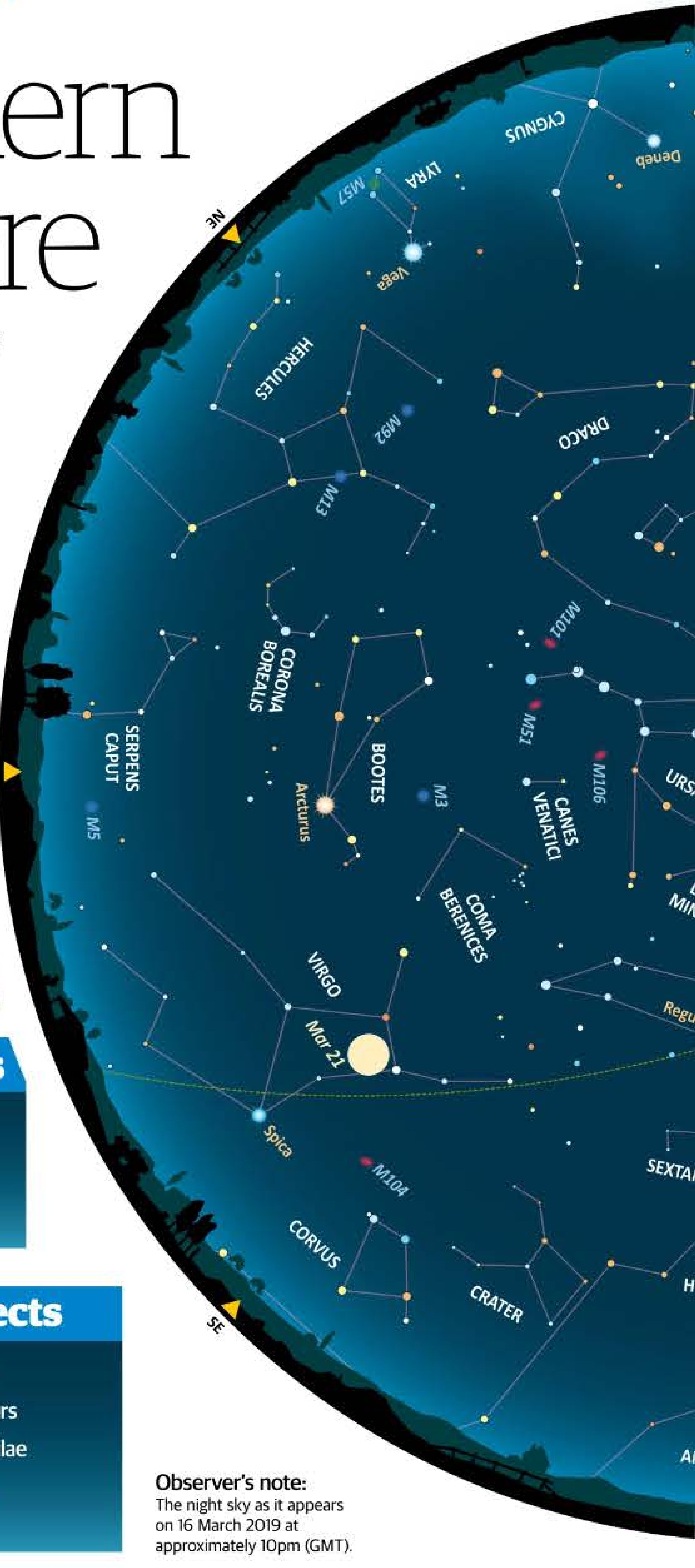
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

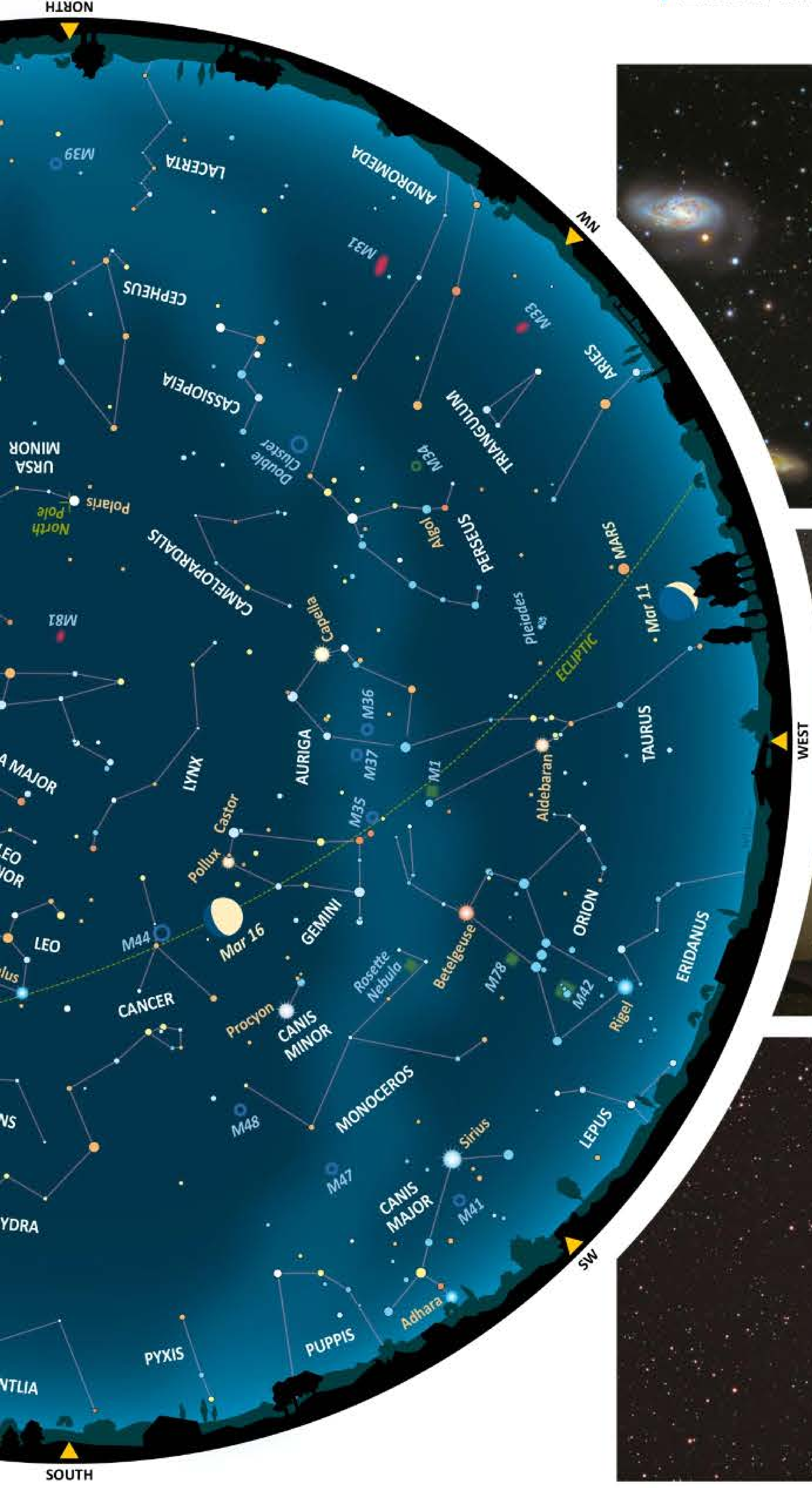
- O-B
- A
- F
- G
- K
- M

Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



Observer's note:
The night sky as it appears on 16 March 2019 at approximately 10pm (GMT).



Leo Triplet (M66 Group)

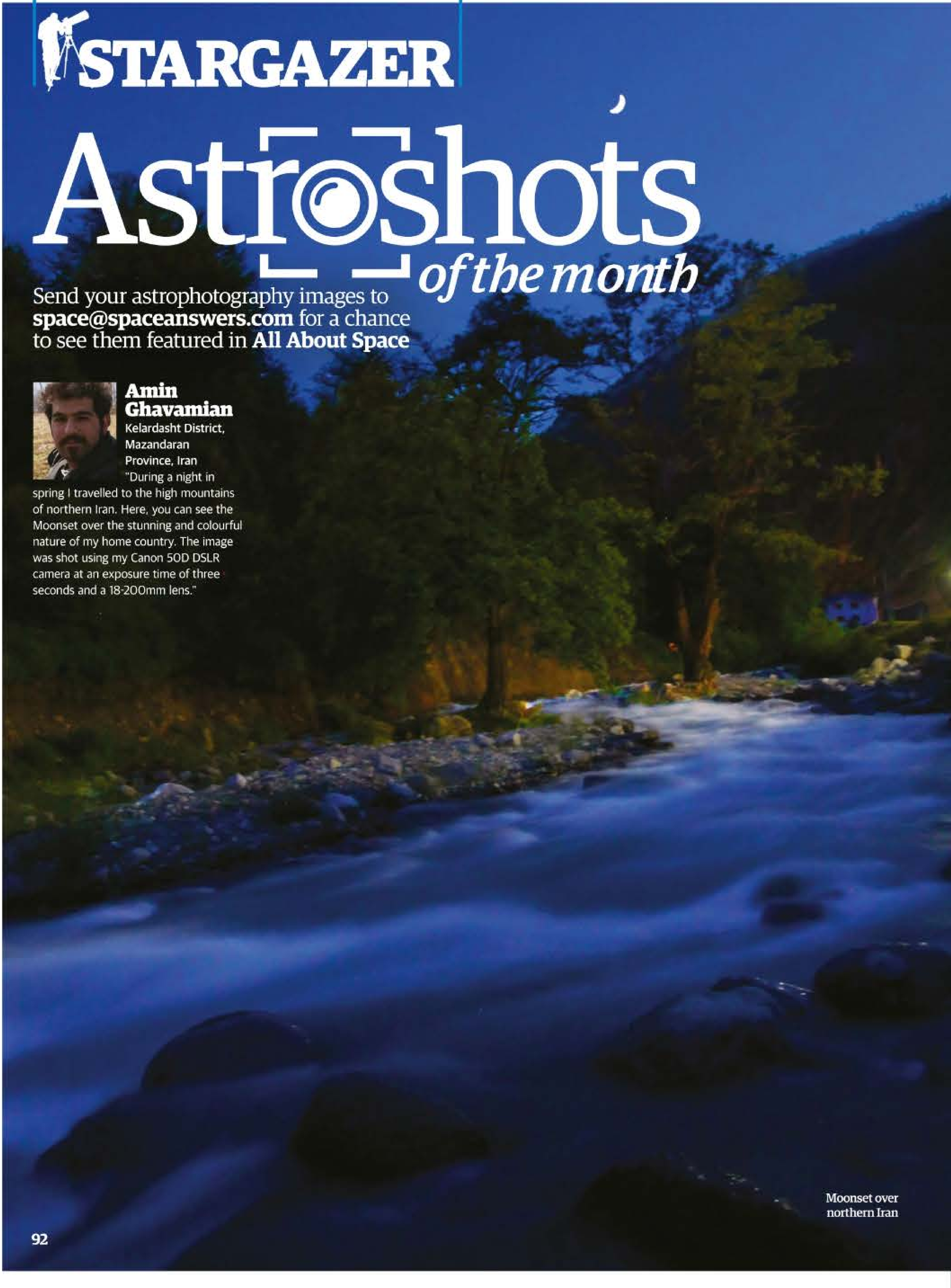
Zodiacal light

Leo dwarf galaxy, near Regulus

© Wil Tirion; ESO; Oliver Stein; Giuseppe Donatiello

Astroshots *of the month*

Send your astrophotography images to **space@spaceanswers.com** for a chance to see them featured in **All About Space**



Amin Ghavamian

Kelardasht District, Mazandaran Province, Iran

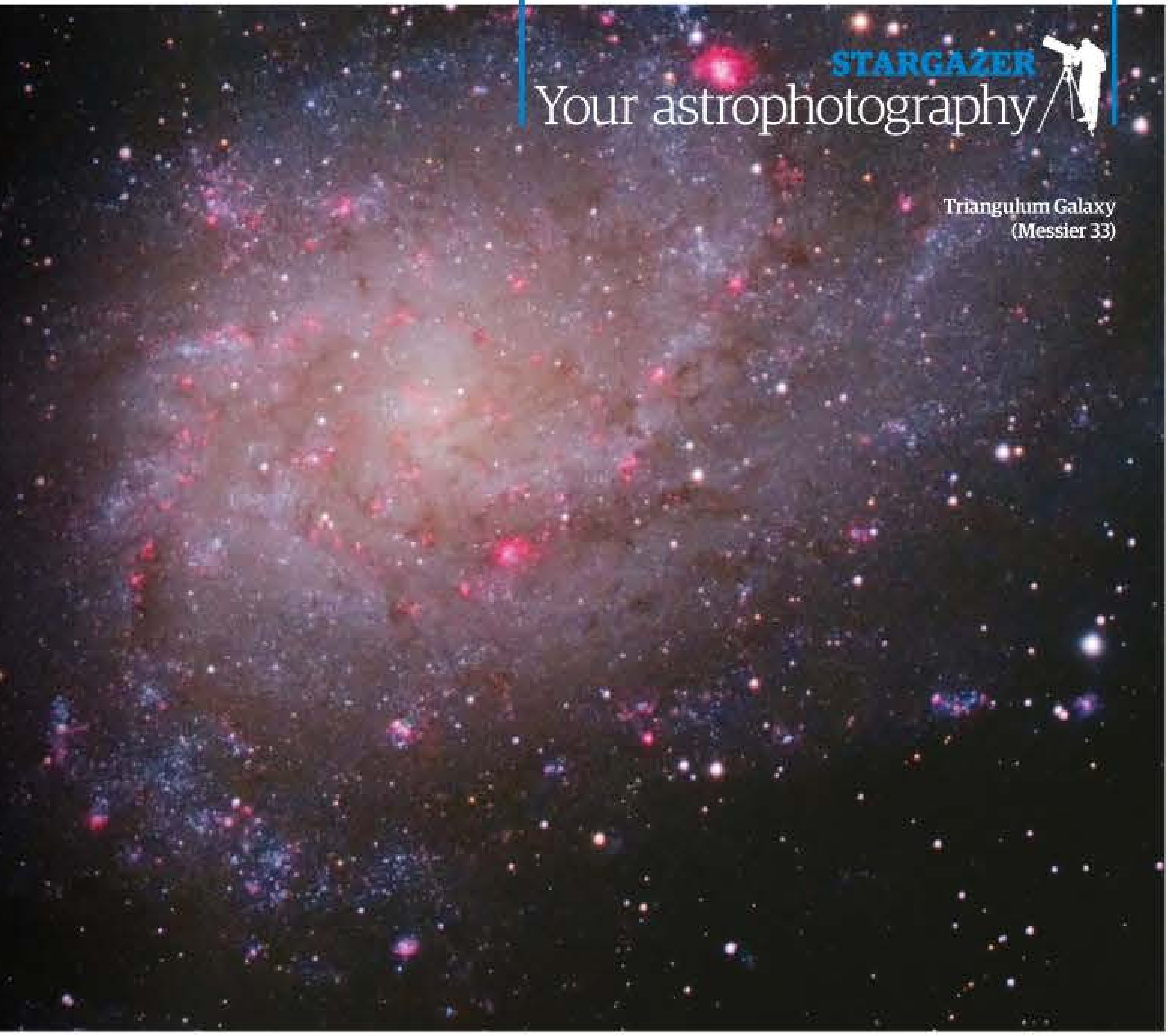
"During a night in spring I travelled to the high mountains of northern Iran. Here, you can see the Moonset over the stunning and colourful nature of my home country. The image was shot using my Canon 50D DSLR camera at an exposure time of three seconds and a 18-200mm lens."

Moonset over northern Iran

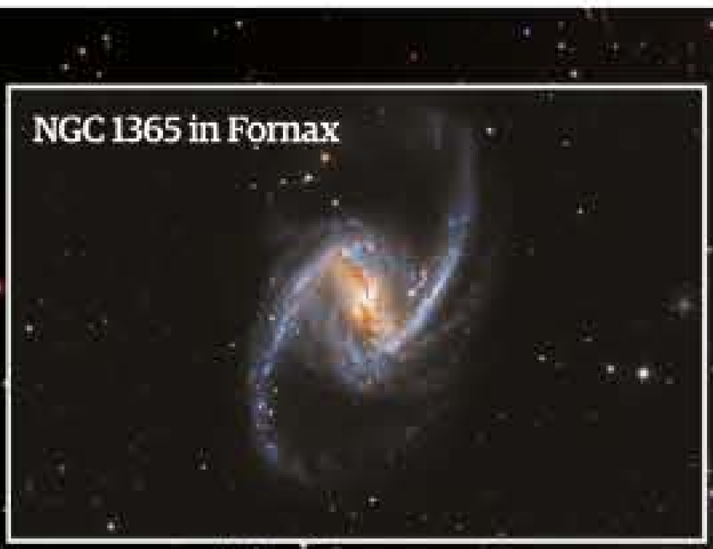
Jeff Johnson

Las Cruces, New Mexico
Telescope: Takahashi TOA-130F refractor

"I have a long love of astronomy and have observed the night sky for many years with binoculars and a telescope from the age of ten. I did my first 'real' astrophotography in 1996 when I used a 35mm SLR camera to take photos of Comet Hyakutake. I took a tripod out into the desert in Las Cruces and just experimented with exposures. Later I bought a ten-inch Dobsonian for viewing, and within a week, was taking pictures through the eyepiece for fun. Within a few more weeks I knew I wanted to get serious with astroimaging."



Triangulum Galaxy (Messier 33)

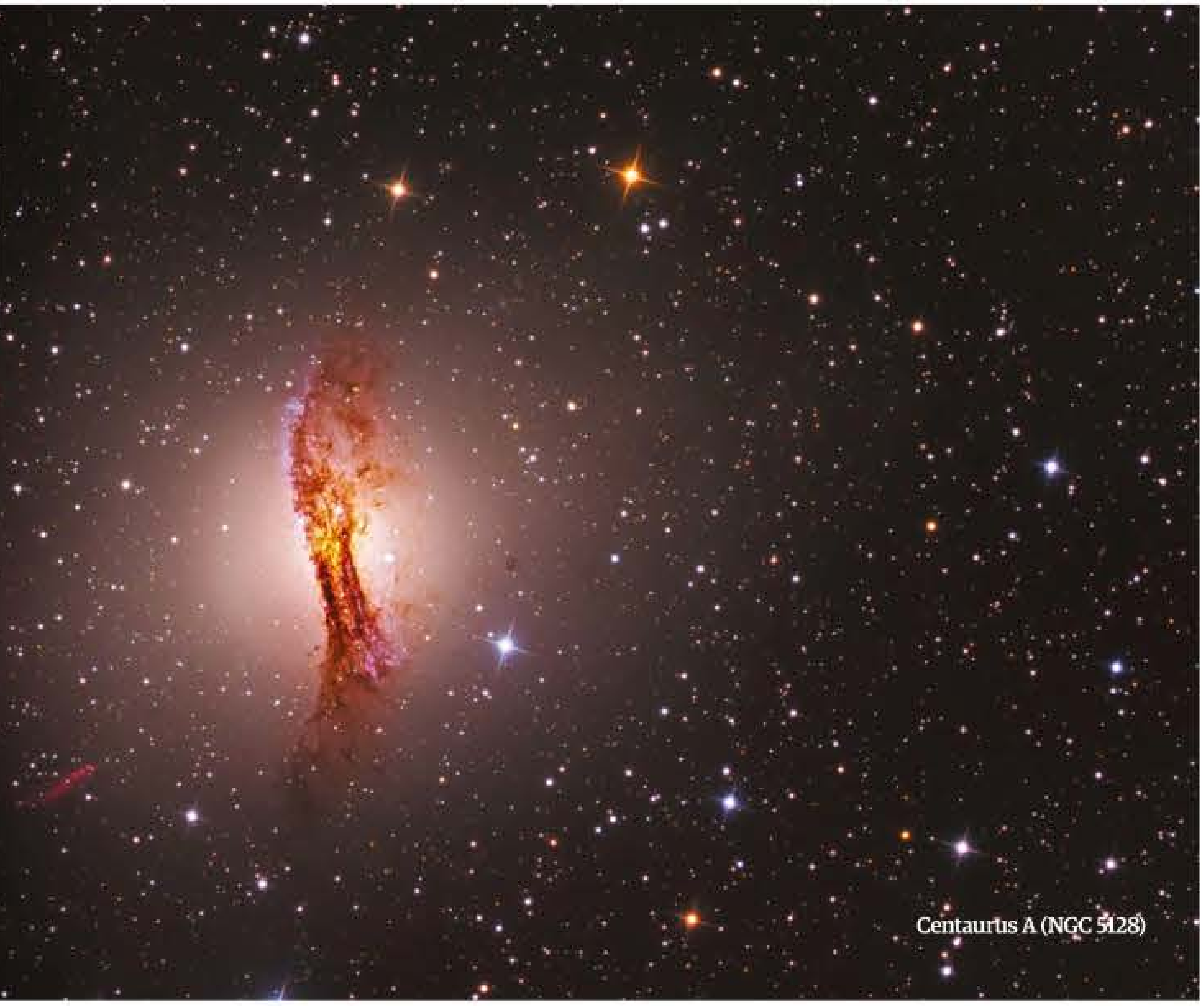


NGC 1365 in Fornax

Warren Keller

West Virginia
Telescope: 16-inch RCOS Ritchey-Chrétien owned by the University of North Carolina

"I began exploring the night sky at the age of 15 years old with an eight-inch Newtonian during the 1960s. It wasn't until 1998 that I got my first taste of astroimaging with film, and in 2003 I switched to a CCD for capturing the treasures of the night sky. Artistic by nature, it's less about cosmology and more about the thrill of the hunt for the myriad beautiful shapes and colours throughout the universe. My astrophotography tutorial business has given thousands a quick start to taking their own great photos."



Centaurus A (NGC 5128)

Send your photos to... @spaceanswers @ space@spaceanswers.com

Celestron PowerSeeker 127 EQ Deluxe

A great beginner's telescope that will resolve details on the Moon, as well as star clusters and bright galaxies

Telescope advice

Cost: £179 (approx. $234)
From: David Hinds Ltd
Type: Reflector
Aperture: 5"
Focal length: 39"

Best for...

- Intermediate
- Small budget
- Solar System targets
- Lunar surface
- Bright deep-sky
- Basic astrophotography

Given the precedent that Celestron has set when it comes to the excellent design and optical systems of their telescopes, we were very much looking forward to trying the PowerSeeker 127 EQ Deluxe out. Even more so since this telescope is a new addition to the market aimed at beginners to the hobby of astronomy.

While many manufacturers are geared more towards Go-To and complicated 'scopes that require tools as well as the nuts and bolts to put them together, it is very refreshing to discover that we were able to put this refractor telescope together in less than ten minutes. What's more, we didn't really need to use the instructions - which are very comprehensive, we might add - since it was so intuitive. There is no need for Allen keys or screwdrivers, and it's easy to fit the 20" tube to the equatorial mount. Extra fixtures such as the finderscope are also a breeze to attach. With a sturdy, collapsible mount and a very lightweight design (as reflectors go!), we recommend this telescope to a family or to those who are looking for a 'grab-and-go' 'scope which can easily be packed up and put in the back of the car. Included in the price are two Plössl eyepieces, a motor drive and smartphone adapter.

On inspecting the telescope once it was set up, the build is fair for the price. As you would expect with many budget telescopes, the PowerSeeker's focusers are made of plastic. While this isn't a massive drawback there are budget telescopes of similar price with higher quality focusers. As for its tripod, this reflector is one that you would need to take extra care with, since it is not as robust as other budget telescopes we have reviewed in **All About Space**. However, the altitude-locking bar, used for keeping everything in place, did a sound job.

As with previous Celestron models that we've taken for a spin under the night sky, we had high hopes for the PowerSeeker's optics. Given the refractor's f/7.87 focal ratio, which offers a wide field of view, we were looking forward to turning the telescope tube to a variety of different targets within reach of its optical limits - bearing in mind its highest useful magnification of 300x and lower end of 18x. With the supplied Plössl eyepieces we were limited to magnifications of 250x and 50x.

Keeping the price of this telescope in mind, we thought that the PowerSeeker's optics were very good for the money, offering very good views with no great issues with coma - the phenomenon where bright targets are distorted, appearing to have a 'tail' akin to comet.

With the last quarter of the Moon in the sky,

Bottom left: The telescope's optics are very good value despite the entry-level cost

Bottom right: The set-up of the telescope is of a sturdy construction

> "We thought that the PowerSeeker's optics were very good for the money"

we took the opportunity to view its craters, which were beautifully picked out by the lunar terminator. As far as clarity goes, this reflector provides quite sharp, bright and clear views that many beginners to astronomy will enjoy and be proud of. The low magnification meant that the lunar surface didn't fill the field of view too much - and means that beginners won't get 'lost' looking at the Moon's surface. The 5x24 finderscope did a satisfactory job in assisting with manually moving across the Moon's surface to provide clearer views. We did find that it was quite small though - something that might put some observers off. However, we thought that the finderscope's size gave a true indication of what the PowerSeeker could achieve, and it was quite capable of picking out faint stars that were ideal for using star-hopping to navigate the night sky.

Swinging the telescope up and down and left to right, the mount was easy to move. However, we did hold the tripod to add a bit of extra stability - just in case - as there was a slight degree of shaking.

Given the telescope's wide field of view, it's capable of picking out star clusters and splitting double stars with ease, akin to a pair of binoculars. We quickly and easily split double stars Alcor and Mizar in Ursa Major and got down to observing star clusters such as the Pleiades, as well as the Orion Nebula. Clear and crisp sights thanks to the exquisite mirrors were had; we felt that this is something that the PowerSeeker excelled at.

Overall the telescope is very good for beginners. The basic standard of extras included made us feel that it would benefit with additional eyepieces to make the most of the upper limits of magnification. Not only that, but a much improved diagonal would benefit the telescope greatly. All in all though, a very good telescope, given the price, and one that'll last for some time as long as it's treated with care.

Above: The supplied 5x24 was found to be extremely useful

Left: The telescope comes equipped with a motor drive

In the shops

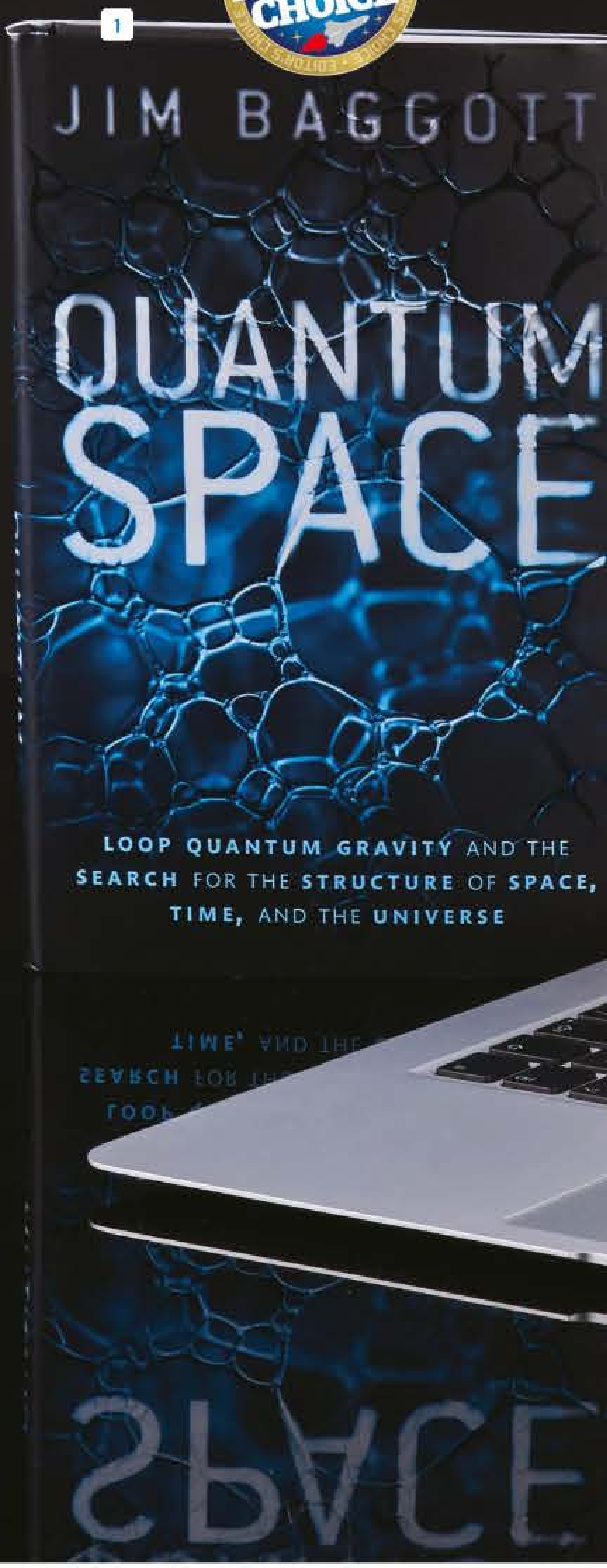
The latest books, apps, software, tech and accessories for space and astronomy fans alike

1. Book Quantum Space

Cost: £20 **From:** Oxford University Press

There's no doubt that Jim Baggott is an excellent popular science writer, specialising in taking complex topics and having a more in-depth look at them in an engaging way. The majority of the time he achieves this with a fluid writing style that remains easily readable, though inevitably there are some aspects that are difficult for the reader to get their head around – this is certainly true of his latest title *Quantum Space*, which takes on loop quantum gravity.

Quantum Space is the first complete and approachable account to a quantum theory and delves deep into the quest to resolve one of the great unanswered problems of modern physics: how can general relativity be made compatible with quantum mechanics? Some may suggest string theory is the answer, but Baggott proposes loop quantum gravity, which in our mind is one of the best explanations of the concept for anyone who wants to understand more about our puzzling universe. Baggott assists anyone who really wants to understand modern theoretical physics, providing a much better understanding of this fascinating attempt to explain the workings of our universe. It's a triumph.


1
JIM BAGGOTT
QUANTUM SPACE
LOOP QUANTUM GRAVITY AND THE SEARCH FOR THE STRUCTURE OF SPACE, TIME, AND THE UNIVERSE

2. App Exoplanet v16.0.1

Cost: Free **From:** iTunes

Highly visual and interactive, Exoplanet allows you to keep up to date with the latest discoveries of alien worlds in the Milky Way. Developed by professional astronomers, this app features a stunning 3D model of our galaxy, revealing the locations of all known exoplanets. We particularly enjoyed the zoom function, which allows the user to get a close-up 'view' of a planetary system. If you've ever wondered what the night sky looks like from these alien worlds then you're in luck: Exoplanet provides such a feature, as well as a push notification when another world is found and where you can find these exoplanets in the night sky in real time.

A database of discoveries, Exoplanet provides detailed information on every confirmed world in a visual way. The app has been consistently revised and improved, fixing any bugs that affect the running, however, despite being in its 16th version it still continues to crash.

3. Book Space Exploration: Past, Present, Future

Cost: £20 **From:** Amberley Publishing

Humanity has always looked to the stars, but it hasn't been until relatively recently that we have managed to travel into space. In writer, producer and CEO of Loch Ness Productions Carolyn Collins Petersen's book, titled *Space Exploration: Past, Present, Future*, the reader is taken on a journey from the first space pioneers and their work, through the First World War-led technological advances in rocketry that formed the basis for the Space Age, to the increasing corporate interest in space. Her detailed examination of human exploration of space is viewed from our potential future there – on Mars to be exact – and considers how we will reach that point. A truly engaging piece of work, *Space Exploration* is a book that's difficult to put down – something that's common among the other books she's co-authored about astronomy and space exploration.

> "Baggott assists anyone who really wants to understand modern theoretical physics"

4. Software **Celestia v1.6.1**

Cost: Free **From:** celestiaproject.net

Celestia brings the universe to your computer, offering a full three-dimensional representation of planets, stars and galaxies, and is based on the Hipparcos catalogue of more than 100,000 stars. What we enjoyed most about this software is that you're not shackled to Earth - Celestia allows you to whizz off in any direction you feel like going, at any speed, whether it's a leisurely stroll or travelling at the speed of light. While the graphics are impressive for a free software we noted that - due to computer memory limitations - Celestia didn't go out much further than 16,000 light years, which meant that we couldn't investigate the 'entire universe' through our computer screens.

Celestia runs on a variety of operating systems including Windows, Linux and Macintosh and features a guided tour of the Solar System, an eclipse finder and much more.

HEROES OF SPACE

Sir James Chadwick

Science wouldn't be the same without the discoverer of the neutral neutron

Chadwick led the British team in the Manhattan Project

To understand the most enormous structures in the universe, such as galaxies, black holes and star clusters, first we need to understand the smallest structures that comprise them - atoms. Atoms are made up of electrons, protons and neutrons, and it is only because of Sir James Chadwick that we are able to understand the neutron, the protagonist of his Nobel Prize-winning discovery.

Chadwick was born on 20 October 1891 in Bollington, England, and lived for 82 years before he passed away peacefully on 24 July 1974. He was a famous physicist who made massive contributions to science, all while being caught up in two world wars.

During the early 20th century Chadwick was spending his time gaining his physics degree under the tutelage of Ernest Rutherford, the famous 'father of nuclear physics', at Victoria University of Manchester. Chadwick worked in Rutherford's laboratory until 1913, where he completed his Master's degree at the age of 22. Afterwards he went to Berlin, Germany, as part of a scholarship to work under Hans Geiger, the inventor of the famous Geiger counter.

In 1914 the First World War had begun, and Chadwick was interned in a camp until the end of the war in 1918. The following year Chadwick teamed up again with Rutherford at Cambridge Laboratory's highly prestigious Cavendish Laboratory.

It was at Cavendish Laboratory where Chadwick made the remarkable discovery of the neutron. During those days it was thought that the atom consisted mostly of protons and electrons. For example, it was thought that a carbon atom contained six electrons and 12 protons. The issue with that was that it would give the carbon atom an electric charge of +6 due to the six extra protons. This is where Chadwick had the thought of having a particle that was of the same mass as a proton, but with no charge.

After hearing of Frédéric and Irène Joliot-Curie's work in ejecting protons using gamma rays Chadwick questioned the nature of that experiment, as it seemed surprising that gamma rays were powerful enough to eject such a particle. This is when he thought that protons were being hit by the particle he was looking for, the neutron. After many experiments on the matter Chadwick discovered the elusive neutron and won the Nobel Prize in Physics in 1935 for his tremendous work.

This discovery altered science for the better because this newly discovered particle could now collide with atomic nuclei. This led to the introduction of isotopes, which are atoms with the same number of protons and electrons but a different number of neutrons. Isotopes of a certain element would therefore exhibit a different mass, and also exhibit different properties. There was also the utilisation of neutrons in splitting apart heavier atoms. This is a process called atomic fission, and it would produce a large amount of energy.

The process of atomic fission came in handy for the development of the atomic bomb, which found Chadwick in the United States helping the Americans with the Manhattan Project. This undeniably impressive work led to his knighthood being granted in 1945 for his wartime contributions, and the United States government also awarded him with a Medal of Merit the following year.

> "It was at Cavendish Laboratory where Chadwick made the remarkable discovery of the neutron"

All About Space

Future PLC Richmond House, 33 Richmond Hill, Bournemouth, Dorset, BH2 6EZ

Editorial
Editor-in-Chief **Gemma Lavender**
gemma.lavender@futurenet.com
01202 586209
Art Editor **Jonathan Wells**
Staff Writer **Lee Cavendish**
Production Editor **Nikole Robinson**
Research Editor **Baljeet Panesar**
Senior Art Editor **Duncan Crook**
Photography **James Sheppard**

Contributors
Stuart Atkinson, Meghan Bartels, Abigail Beall, David Crookes, Ian Evenden, Kelly Oakes, Nola Taylor Redd, Mike Wall

Cover images
Tobias Roetsch; Adrian Mann, NASA/JPL-Caltech

Photography
Alamy; ESA; ESO; NASA; Science Photo Library; Shutterstock; SpaceX; University of Arizona; Wikipedia Commons;
All copyrights and trademarks are recognised and respected

Advertising
Media packs are available on request
Commercial Director **Clare Dove**
clare.dove@futurenet.com
Regional Advertising Director **Mark Wright**
mark.wright@futurenet.com
Account Director **Andy Baker**
andy.baker@futurenet.com
01225 687 520
Account Manager **Jagdeep Maan**
jagdeep.maan@futurenet.com
01225 687 353

International Licensing
All About Space is available for licensing. Contact the Licensing team to discuss partnership opportunities.
Head of Print Licensing
Rachel Shaw licensing@futurenet.com

Subscriptions
Email enquiries **contact@myfavouritemagazines.co.uk**
UK orderline & enquiries **0344 848 2852**
Overseas order line and enquiries **+44 (0)344 848 2852**
Online orders & enquiries **www.myfavouritemagazines.co.uk**
Head of subscriptions **Sharon Todd**

Circulation
Head of Newstrade **Tim Mathers**

Production
Head of Production **Mark Constance**
Production Project Manager **Clare Scott**
Advertising Production Manager **Joanne Crosby**
Digital Editions Controller **Jason Hudson**
Production Manager **Frances Twentyman**

Management
Chief Content Officer **Aaron Asadi**
Commercial Finance Director **Dan Jotcham**
Managing Director **Alastair Lewis**
Head of Art & Design **Greg Whitaker**

Printed by Wyndeham Peterborough, Storey's Bar Road, Peterborough, Cambridgeshire, PE1 5YS

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU www.marketforce.co.uk Tel: 0203 787 9060

ISSN 2050-0548

We are committed to only using magazine paper which is derived from responsibly managed, certified forestry and chlorine-free manufacture. The paper in this magazine was sourced and produced from sustainable managed forests, conforming to strict environmental and socioeconomic standards. The manufacturing paper mill holds full FSC (Forest Stewardship Council) certification and accreditation

All contents © 2019 Future Publishing Limited or published under licence. All rights reserved. No part of this magazine may be used, stored, transmitted or reproduced in any way without the prior written permission of the publisher. Future Publishing Limited (company number 2008885) is registered in England and Wales. Registered office: Quay House, The Ambury, Bath BA1 1UA. All information contained in this publication is for information only and is, as far as we are aware, correct at the time of going to press. Future cannot accept any responsibility for errors or inaccuracies in such information. You are advised to contact manufacturers and retailers directly with regard to the price of products/services referred to in this publication. Apps and websites mentioned in this publication are not under our control. We are not responsible for their contents or any other changes or updates to them. This magazine is fully independent and not affiliated in any way with the companies mentioned herein.

If you submit material to us, you warrant that you own the material and/or have the necessary rights/permissions to supply the material and you automatically grant Future and its licensees a licence to publish your submission in whole or in part in any/all issues and/or editions of publications, in any format published worldwide and on associated websites, social media channels and associated products. Any material you submit is sent at your own risk and, although every care is taken, neither Future nor its employees, agents, subcontractors or licensees shall be liable for loss or damage. We assume all unsolicited material is for publication unless otherwise stated, and reserve the right to edit, amend, adapt all submissions.

FUTURE
Connectors.
Creators.
Experience
Makers.

Future plc is a public
company quoted on the
London Stock Exchange
(symbol: FUTR)
www.futureplc.com

Chief executive **Zillah Byng-Thorne**
Non-executive chairman **Richard Huntingford**
Chief financial officer **Penny Ladkin-Brand**

Tel +44 (0)1225 442 244

OPTICS OF DISTINCTION

OSTARA

ELINOR

The award winning Elinor range has it all with an ultra wide field of view providing a high resolution, comfortable and an incredibly stable image. Features include large eyepiece lenses for very comfortable, long eye relief viewing.
The body has tough rubber armour and is waterproof.

All surfaces are fully multicoated further enhancing brightness and clarity. Optical Hardware's broad lightband transmission ensures incredibly accurate colour rendition.

30 YEAR GUARANTEE

Available in a choice of magnifications
7x50 | 8x45 | 10x50 | 12x50

OPTICAL HARDWARE

Ostara binoculars are manufactured and distributed by Optical Hardware Ltd.
For more information and to find your nearest stockists, please visit **www.opticalhardware.co.uk/stockists**
All offers are subject to availability, prices and specifications are subject to change without notice. E&O.E. Your statutory rights are not affected.

Sky-Watcher® Performance, Precision and Value

Sky-Watcher is a First-Class telescope brand offering an incredible range of high-quality astronomical telescopes and accessories, catering for users of all age groups and abilities, from the novice right up to the serious advanced astronomer. Sky-Watcher astronomical telescopes perfectly integrate modern optical technology with precision mechanical engineering, resulting in designs of suberb functionality, versatility and uncompromising levels of performance.

EXPLORER-130 & EXPLORER-130M 130mm (5.1") F/900 NEWTONIAN REFLECTOR TELESCOPES

- Magnifications (with optics supplied): x36, x72, x90, x180
- Highest Practical Power (Potential): x260
- Diameter of Primary Mirror: 130mm
- Telescope Focal Length: 900mm (f/6.92)
- Eyepieces Supplied (1.25"): 10mm & 25mm
- x2 Barlow Lens
- 30% more Light Gathering than 114mm
- R.A. Motor Drive With Multi-Speed Handset (Explorer-130M only)
- Red Dot Finder
- EQ2 Equatorial Mount
- Aluminium Tripod with Accessory Tray

Sky at Night GROUP TEST WINNER

Explorer-130 Model

Explorer-130M Model illustrated

EXPLORER-130
(Without R.A. Motor Drive)
Prod.Code 10922

SRP £189

EXPLORER-130M
(With R.A. Motor Drive)
Prod.Code 10713

SRP £229

> *"Every class of object we viewed could be seen clearly… Taking everything into account, this telescope made observing the night sky enjoyable… great views coupled with ease of use."*
> **BBC Sky at Night Magazine**

PARABOLIC REFLECTORS – PREMIUM FEATURES

Both the SKYHAWK-1145P & EXPLORER-130P models below offer excellent all-round performance on The Moon, Planets & Deep Sky Objects. They feature premium quality Parabolic Primary Mirrors to eliminate spherical aberrations, producing even sharper, higher-contrast images which are full of detail. A "Paraboloidal" mirror is ground to a complex shape which brings all incoming light rays to a perfect focus, on axis. In addition they feature 0.5mm Ultra-Thin secondary mirror supports, to reduce diffraction spikes and light loss.

SKYHAWK-1145P 114mm (4.5") F/500

PARABOLIC NEWTONIAN REFLECTOR TELESCOPE

- Magnifications (with optics supplied): x20, x40, x50, x100
- Highest Practical Power (Potential): x228
- Diameter of Primary Mirror: 114mm
- Telescope Focal Length: 500mm (f/5)
- Eyepieces Supplied (1.25"): 10mm & 25mm
- x2 Barlow Lens
- Parabolic Primary Mirror
- 0.5mm Ultra-Thin Secondary Mirror Supports
- Red Dot Finder
- EQ1 Equatorial Mount
- Aluminium Tripod with Accessory Tray
- 125% more Light Gathering than 76mm

Sky at Night GROUP TEST WINNER

Prod.Code 10709

SRP £159

> *"The optics were so good... Captures star clusters and brighter nebulae beautifully... The planet (Saturn) was jaw-droppingly beautiful, with a host of fine detail visible... The review instrument certainly delivered in every important respect."*
> **BBC Sky at Night Magazine**

EXPLORER-130P

130mm (5.1") F/650 PARABOLIC NEWTONIAN REFLECTOR TELESCOPE

- Magnifications (with optics supplied): x26 & x65
- Highest Practical Power (Potential): x260
- Diameter of Primary Mirror: 130mm
- Telescope Focal Length: 650mm (f/5)
- Eyepieces Supplied (1.25"): 10mm & 25mm
- Parabolic Primary Mirror
- 0.5mm Ultra-Thin Secondary Mirror Supports
- Red Dot Finder
- EQ2 Equatorial Mount
- Aluminium Tripod with Accessory Tray
- 30% more Light Gathering than 114mm

Astronomy HOT Product

Prod.Code 10712

SRP £229

> *"I was most impressed by the views revealed by the 'scope during tests… Despite a phase of nearly 96 percent, the waxing gibbous Moon revealed a seemingly inexhaustible amount of fine detail... Highly recommended!"*
> **Astronomy Now Magazine**

Sir Patrick Moore Endorsed Sky-Watcher Telescopes

> *"I have used a great number of telescopes; some are good, some mediocre and some bad. To me the Sky-Watcher range of instruments are very good indeed, & suited to amateurs of all kinds - and they are not priced out of the market! Excellent value. Use them and enjoy them."*
> **Sir Patrick Moore CBE FRS (1923-2012)**

76 page Full Colour Catalogue

COMPREHENSIVE COLOUR CATALOGUE with Full Details of our EXTENSIVE PRODUCT RANGE as well as Helpful Information & Advice

Order Your FREE Copy Today

FAX: 01359 244255
EMAIL: info@opticalvision.co.uk

Our Products are Available from Dealers throughout the UK OVL **Please contact us, or Check our Website for your Nearest Stockist**

OPTICAL VISION LTD
UNIT 3, WOOLPIT BUSINESS PARK
WOOLPIT, BURY ST. EDMUNDS
SUFFOLK IP30 9UP

OPTICAL VISION LIMITED
www.opticalvision.co.uk
www.barrandstroud.com

Importers and Distributors of Sky-Watcher Astronomical Telescopes, Helios, Acuter, Barr and Stroud Binoculars & Spotting Scopes and 'Zenith' Microscopes.